PACE: Mission Objectives

PACE

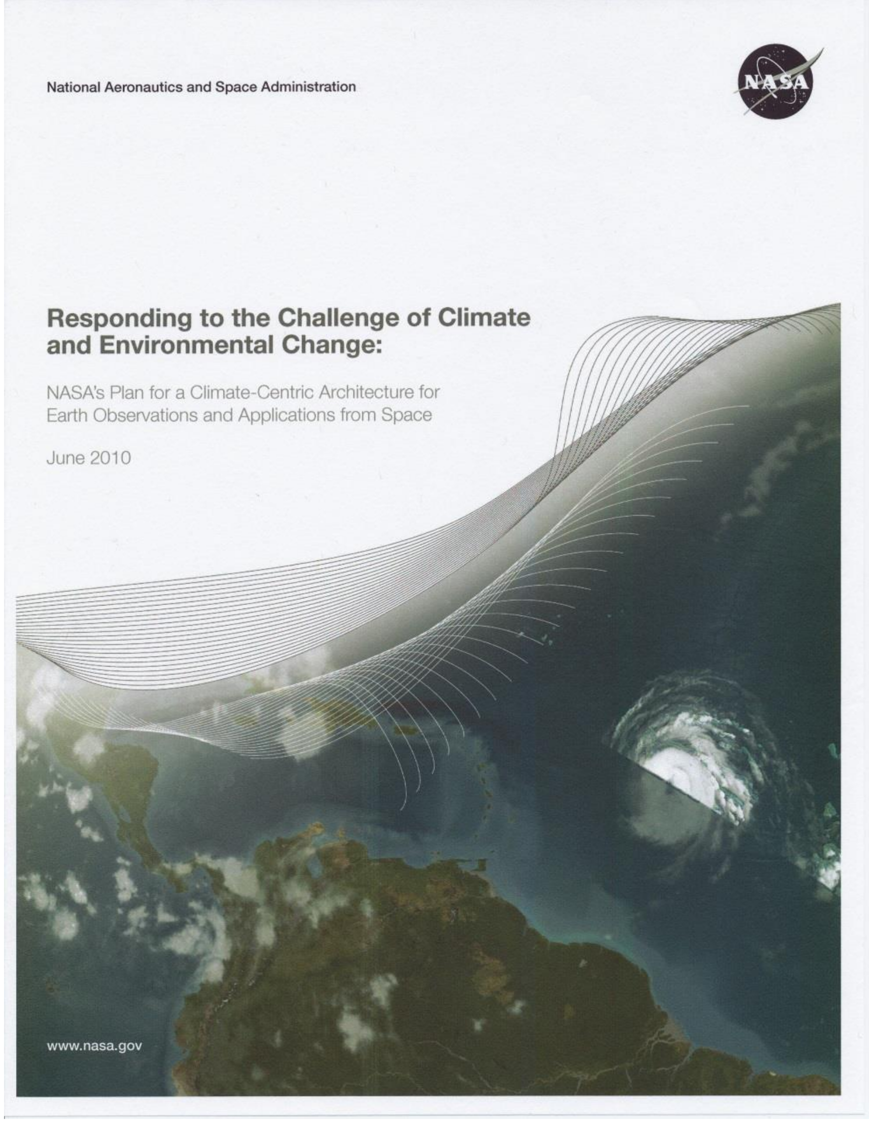
Pre-Aerosol Cloud ocean Ecology mission

Ocean Ecology & Carbon

"New and continuing global observations of ocean ecology, biology, and chemistry are required to quantify aquatic carbon storage and ecosystem function response to human activities and natural events." page 18

"…allow NASA to provide for early flight of a highly calibrated Ocean Ecosystem Spectroradiometer (OES) designed to provide climate-quality radiances that can be used to make quantitative measurements of ocean productivity and related parameters… ." page 34

"This mission will include a radiometer optimized for studies of ocean productivity… ." page 36



PACE: Mission Objectives

PACE

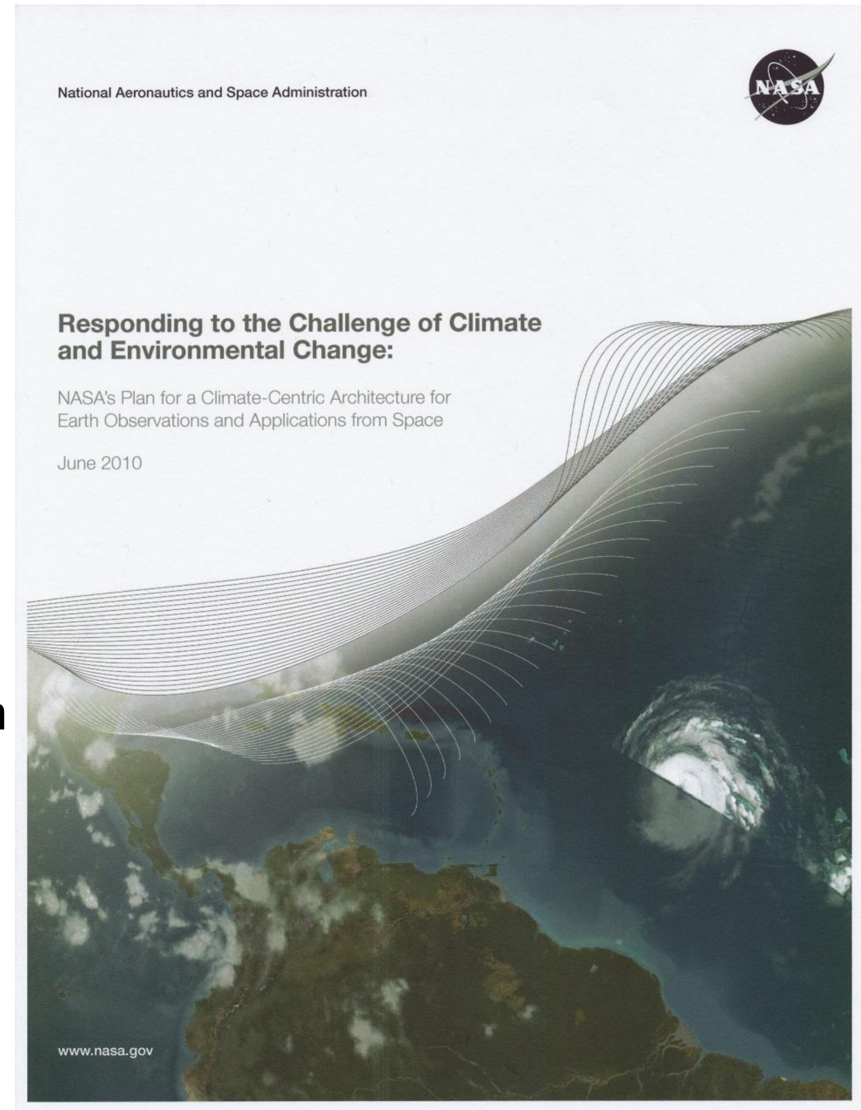
Pre-Aerosol Cloud ocean Ecology mission

Ocean Ecology & Carbon

"The Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) mission will make essential global ocean color measurements, essential for understanding the carbon cycle and how it both affects and is affected by climate change, along with polarimetry measurements to provide extended data records on clouds and aerosols."

"…A polarimeter instrument will extend data records on aerosols and clouds using this approach begun by the French PARASOL mission and expanded upon by NASA's planned Glory mission … ." page 18

Recognizing the synergy of polarimetric measurements with the primary ocean color radiometer observations.


National Aeronautics and Space Administration

NASA

Responding to the Challenge of Climate and Environmental Change:

NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space

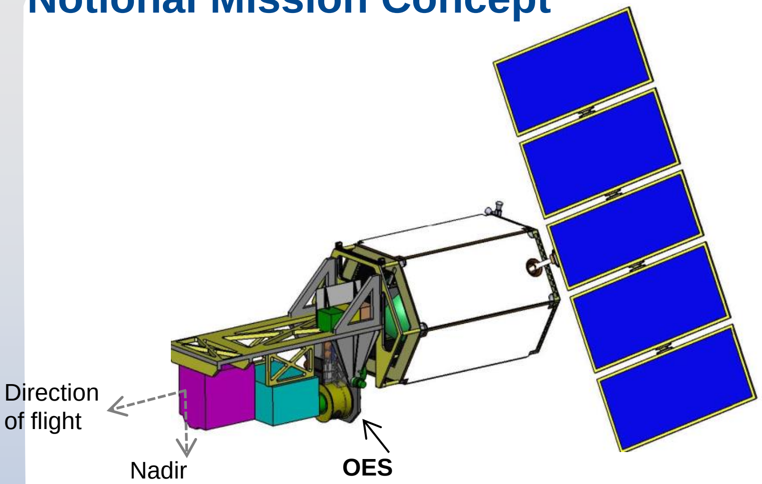
June 2010

www.nasa.gov

Pre-Aerosol, Cloud, Ecosystem Mission (PACE) *PACE*

Pre-Aerosol Cloud ocean Ecology mission

Notional Mission Concept



Overview

- Extend and expand key ocean biogeochemical, biological, and aerosol climate data records. PACE will make global ocean color measurements, essential for understanding the carbon cycle and ocean ecosystem structure and how these affect and are affected by climate change, along with polarimetry measurements to provide enhanced data records on clouds and aerosols.
- The PACE mission is looking at a launch date no earlier than 2022 although given the demise of SEAWiFS and anticipated loss of MODIS in the next several years, it could be accelerated. Mature technology exists that allows earlier mission implementation – launch in 2016 or 2017 timeframe.

Mission

- PACE will continue Goddard's long term contribution to the study and observation of ocean ecology, clouds, and aerosols.
- Climate data processing and archiving are capabilities already in place at GSFC.
- In situ data collection for OES and polarimeter algorithm development and product validation already is in place at GSFC.
- Synergy of OES and polarimetry measurements.

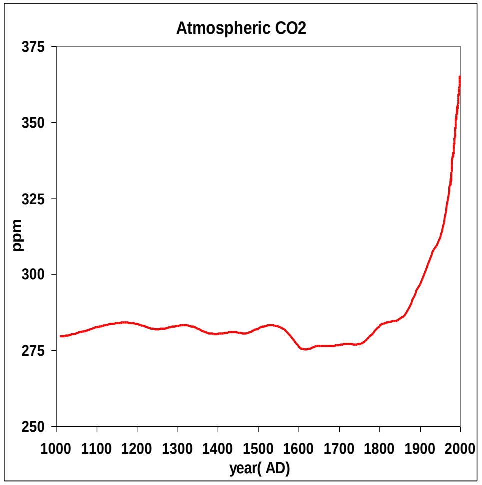
Instruments/Payload

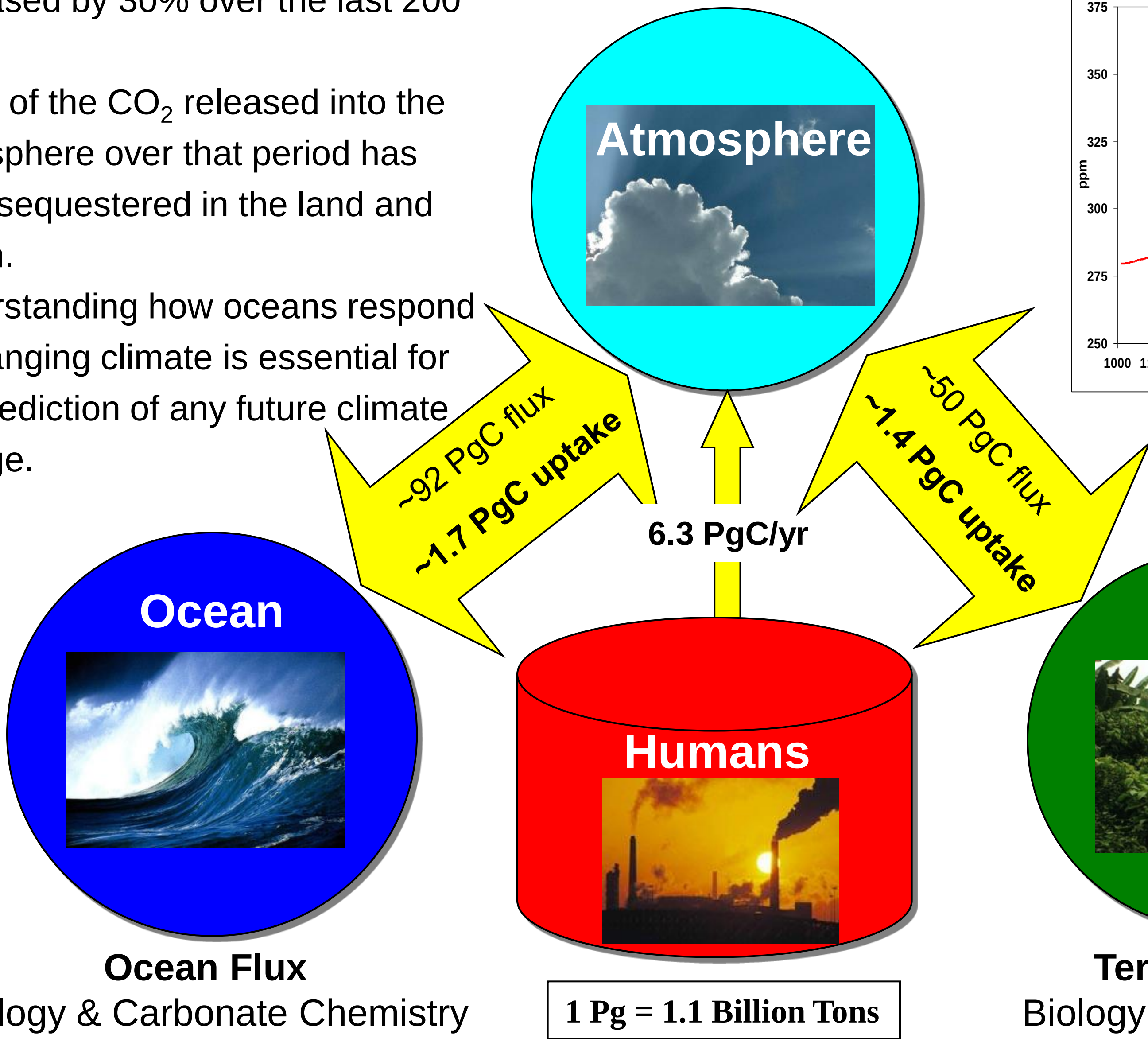
- **Ocean Ecology Sensor (OES)**
  - ➢ GSFC has the leading OES instrument candidate, Ocean Radiometer for Carbon Assessment (ORCA), likely to be the ocean color sensor that is selected.
- **Polarimeter**
  - ➢ No polarimeter
  - ➢ The polarimeter is directed to the Jet Propulsion Laboratory (JPL);
  - ➢ The polarimeter is competed(GSFC excluded);
  - ➢ The polarimeter is contributed (which could include from a foreign partner)

Global Carbon Budgets

Pre-Aerosol Cloud ocean Ecology mission

- Carbon dioxide concentrations have increased by 30% over the last 200 years
- ~50% of the CO_2 released into the atmosphere over that period has been sequestered in the land and ocean.
- Understanding how oceans respond to changing climate is essential for the prediction of any future climate change.

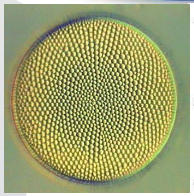


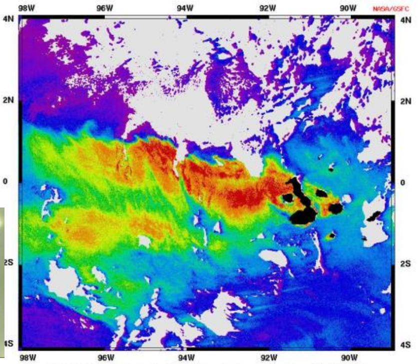


Ocean Biology and Carbon

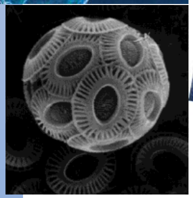
PACE

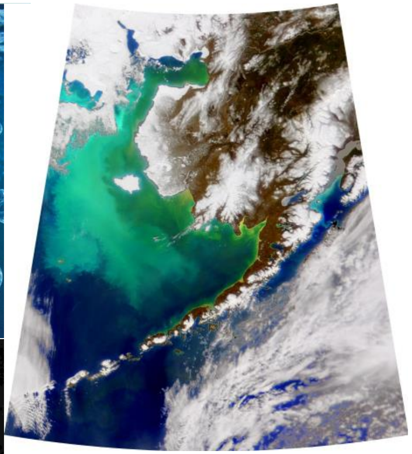
Pre-Aerosol Cloud ocean Ecology mission





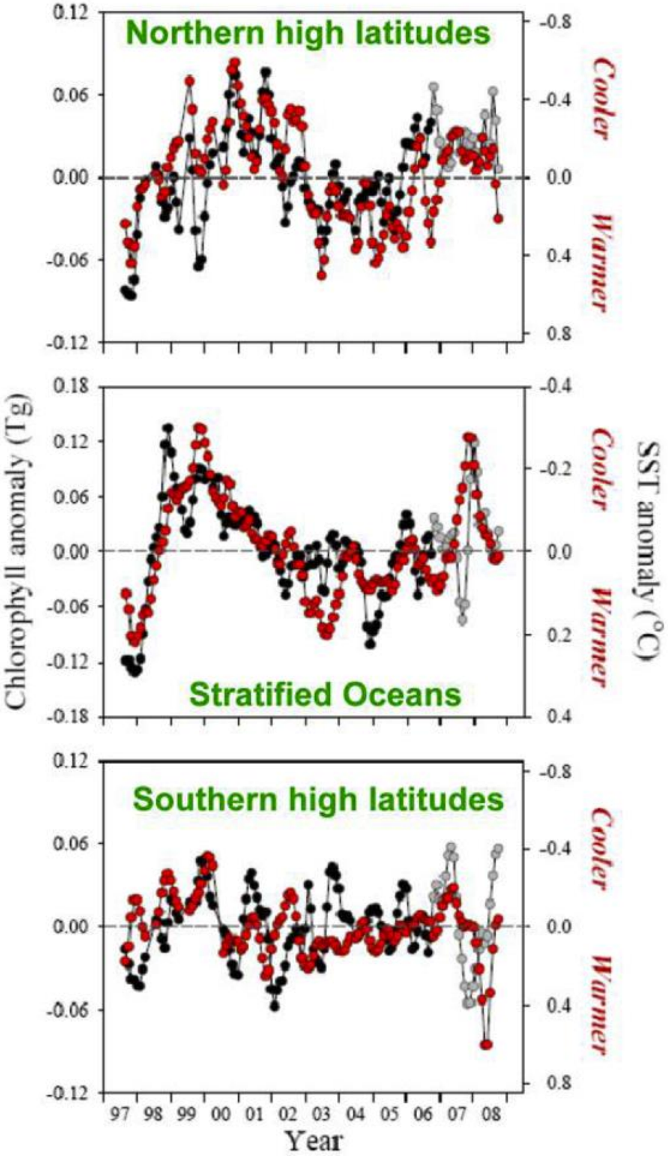
Diatoms





Coccolithophores

- Phytoplankton are 1% of global biomass, but nearly **HALF** the net global photoynthesis.
- How phytoplankton productivity responds to changing ocean temperatures and acidity is one of the key elements in understanding carbon uptake by the oceans
- **BUT** the relationship between optical properties and productivity is complicated and currently not accurately described or quantified



Quantifying Ocean Productivity

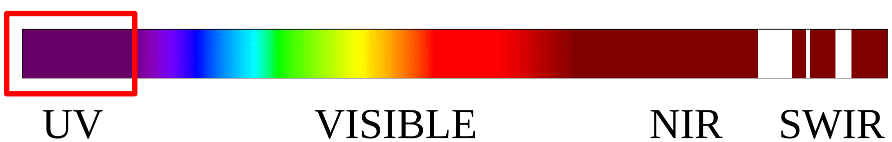
PACE

Pre-Aerosol Cloud ocean Ecology mission

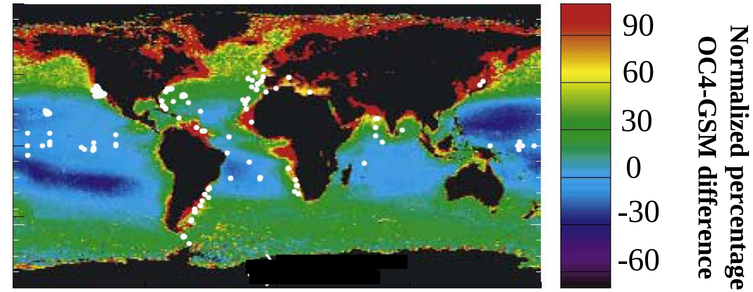
Objective: Accurate separation of pigments and colored dissolved organic matter (cDOM)

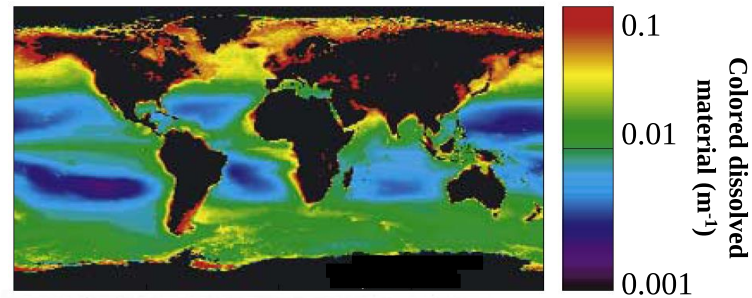
Current Status: Uncertainty in pigment-cDOM retrievals introduce ocean productivity uncertainty of order **10 Pg C y^{-1} or ~ 20%.**

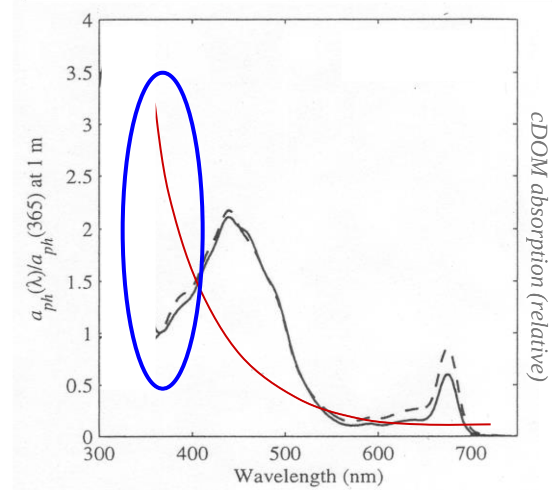
Approach: Measurements in *near-UV* will enable more accurate separation of absorbing compounds



Jacek will talk more about this







Understanding Ocean Productivity

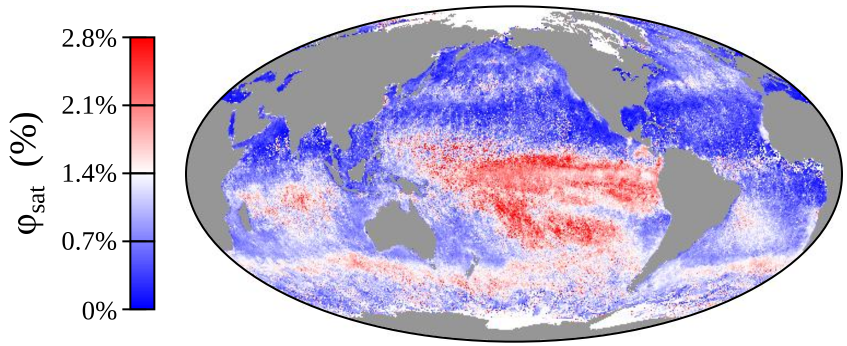
PACE

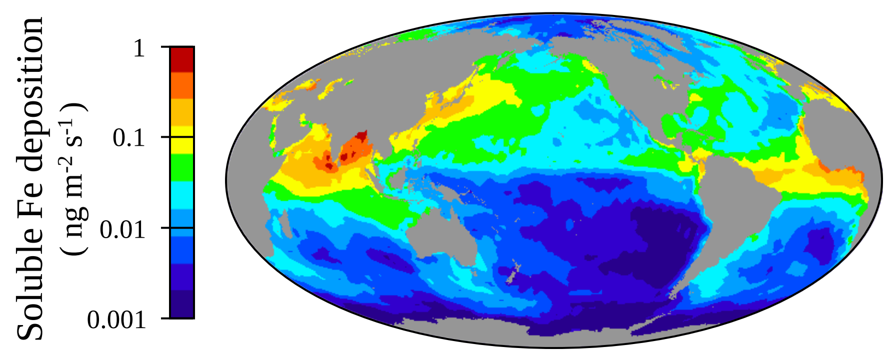
Pre-Aerosol Cloud ocean Ecology mission

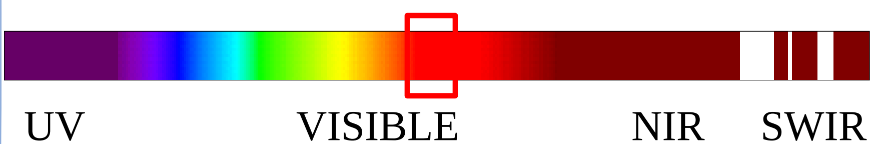
Objective: Evaluate aeolian iron fertilization of ocean ecosystems

Current Status: MODIS Aqua data reveal high phytoplankton fluorescence yields under low iron conditions, allowing study of aeolian fertilization effects. However, VIIRS does not have fluorescence bands

Approach: Include chlorophyll fluorescence detection bands







Understanding Ocean Productivity

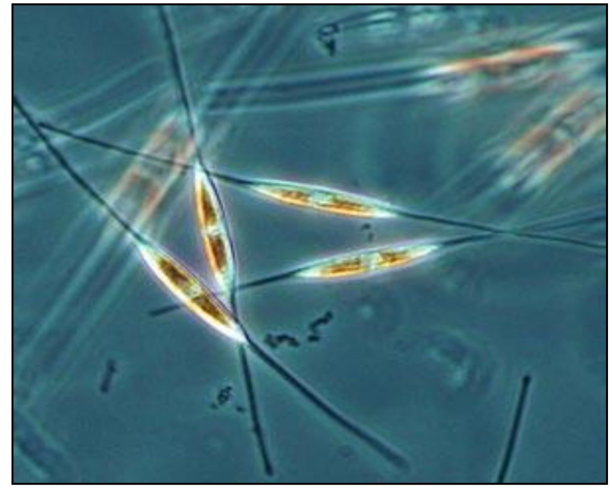
PACE

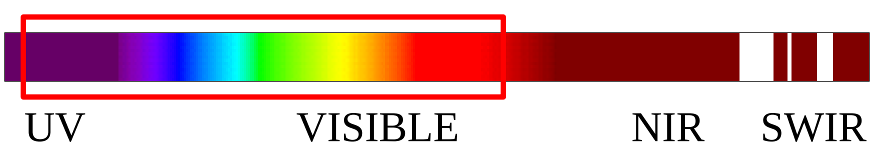
Pre-Aerosol Cloud ocean Ecology mission

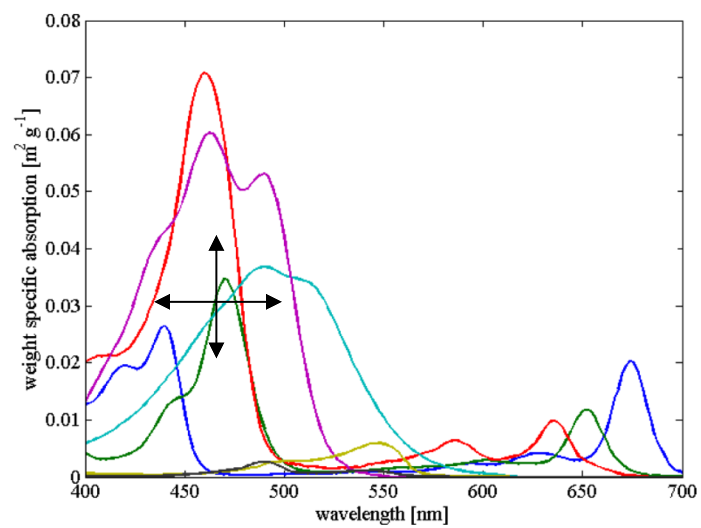
Objective: Determine global distribution of key phytoplankton "functional" groups, the bases for marine food webs, fisheries, etc.

Current Status: Distributions of phytoplankton populations vary globally and are changing with warming trends. Heritage satellite sensors do not have the spectral coverage required to identify different phytoplankton "functional" types.

Approach: Increase spectral *resolution in the UV-red region* identify various phytoplankton pigments associated with different groups. Also, see next slide on data products.







Science Questions to Data Products

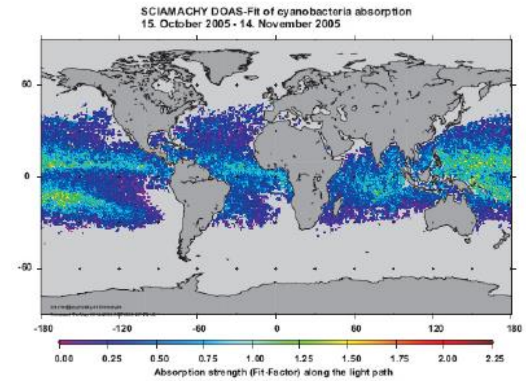
PACE

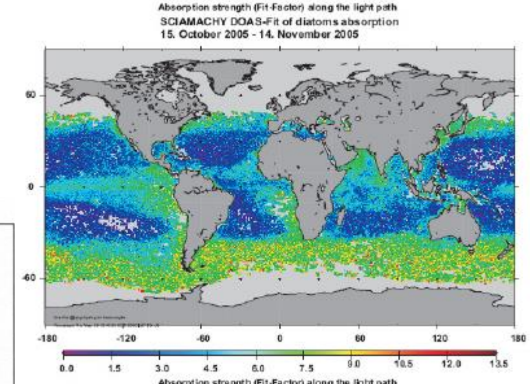
Pre-Aerosol Cloud ocean Ecology mission

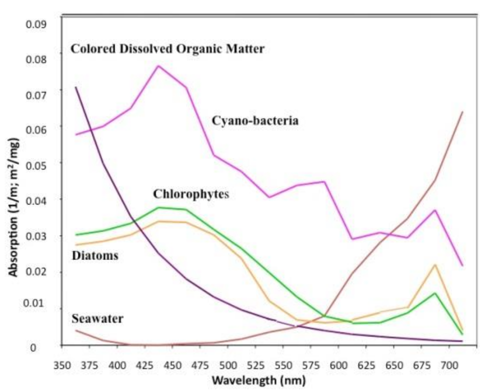
Requirements Flowdown: Relationship between optical, biological, & biogeochemical parameters required to answer science questions and measurement requirements is well understood and captured in ORCA design, which will transform the study of oceans from satellite instruments.

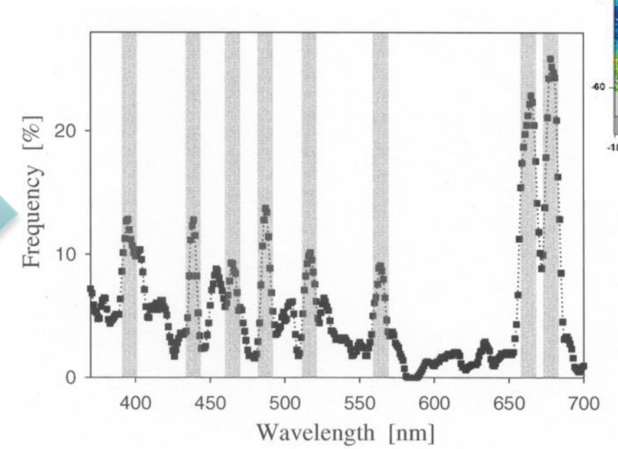
- e.g. Functional group derivative analyses require 5 nm data

Global distributions of functional groups









Science Questions to Data Products

PACE

Pre-Aerosol Cloud ocean Ecology mission

PACE Baseline

Present Baseline of Validated Products (SeaWiFS & MODIS)

- Normalized water-leaving radiances
- Chlorophyll-a
- Diffuse attenuation coefficient (490 nm)

Current Unvalidated Research Products

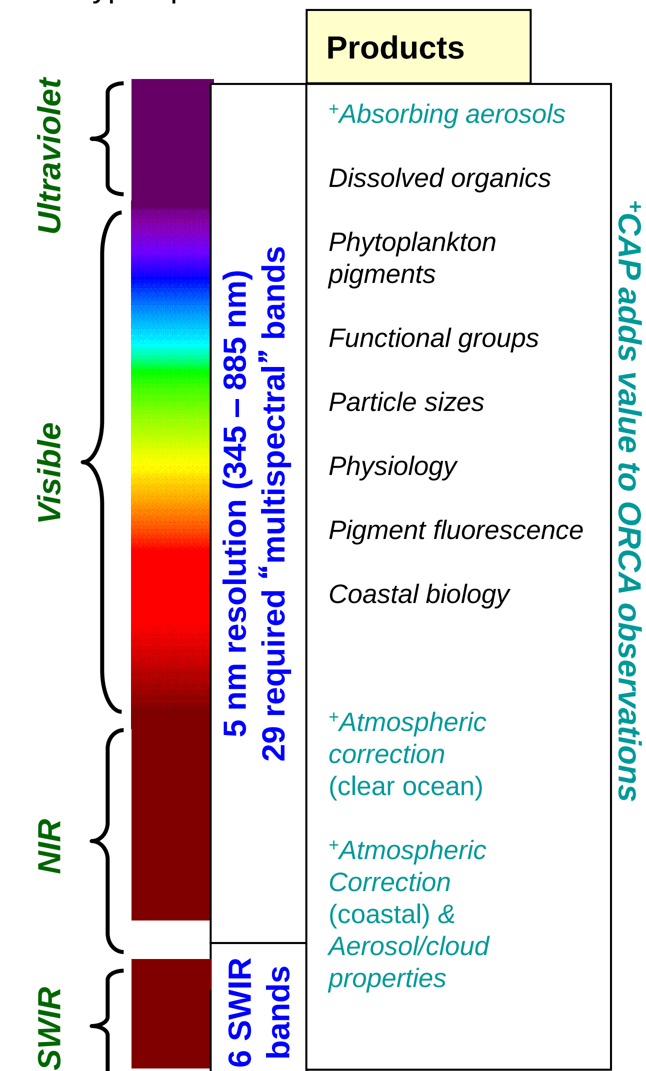
- Inherent optical properties
- Spectral diffuse attenuation
- Euphotic depth
- Spectral remote sensing reflectance
- Particulate organic carbon concentration
- Primary production
- Calcite concentration
- Colored dissolved organic matter
- Photosynthetically available radiatio
- Fluorescence line height
- Total suspended matter
- Trichodesmium concentration

PACE Research Products

- Particle size distributions & composition
- Phytoplankton carbon
- Dissolved organic matter/carbon
- Physiological properties
- Phytoplankton pigment absorption spectra
- Export production
- Functional/Taxonomic groups

ORCA (PACE)*

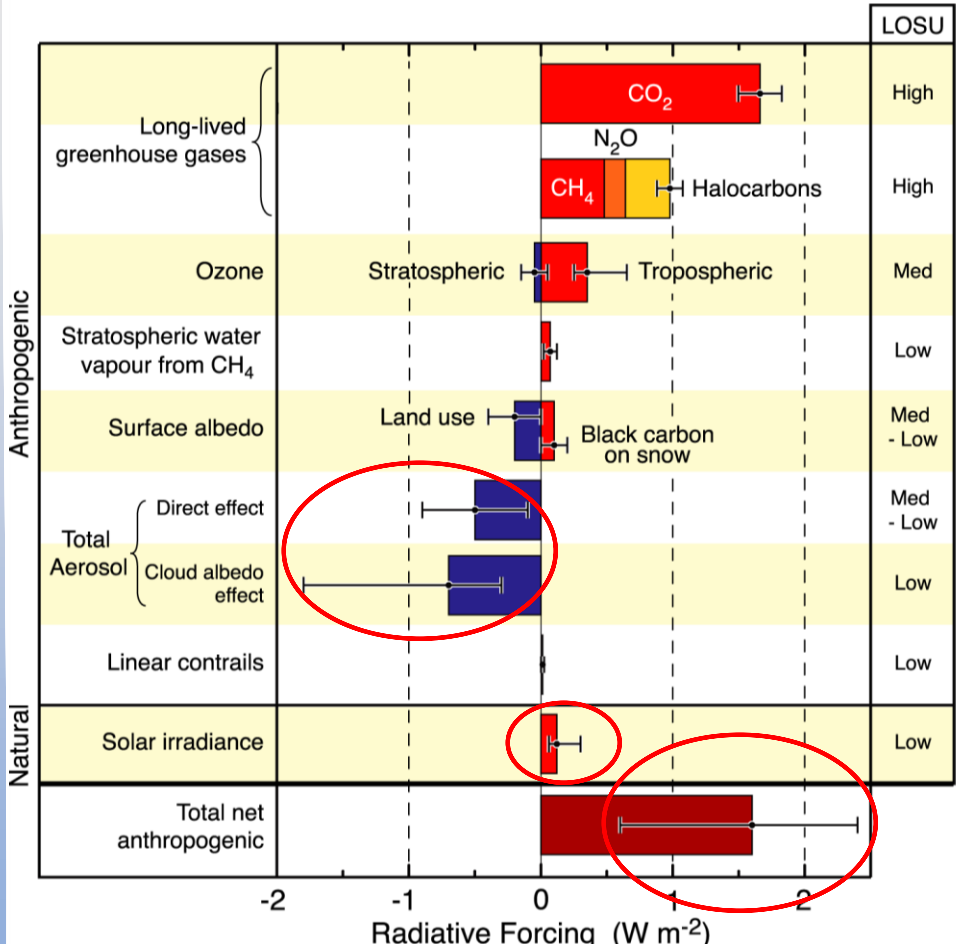
108 “hyperspectral” bands + 6 SWIR bands



* Pending PACE SDT recommendations

Radiative Forcings

PACE
Pre-Aerosol Cloud ocean Ecology mission



IPCC Summary for Policymakers, 2007

- Realistic estimates of the net aerosol forcing over the 20th century based on the observed warming **range between –1.2 and –2.0 Wm^{-2}**.
- Range is caused by different assumptions about how fast the oceans respond.
- If we clean up the air* we may have a relatively small effect (-0.6 Wm^{-2}) on climate relative to CO_2, or almost double the forcing (-1.0 Wm^{-2}).
- Role of aerosols is the largest uncertainty in radiative forcing.

*Reduce forcing by 50%

Quantifying Radiative Forcings

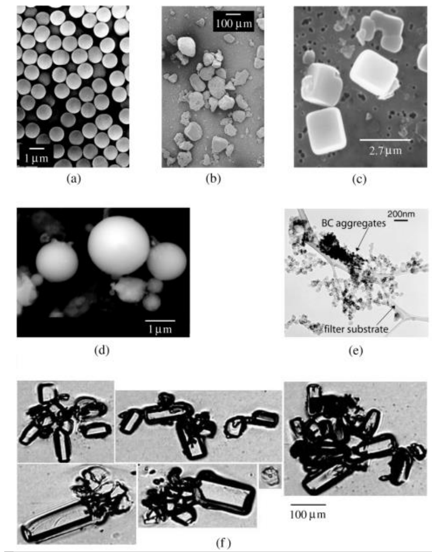
PACE

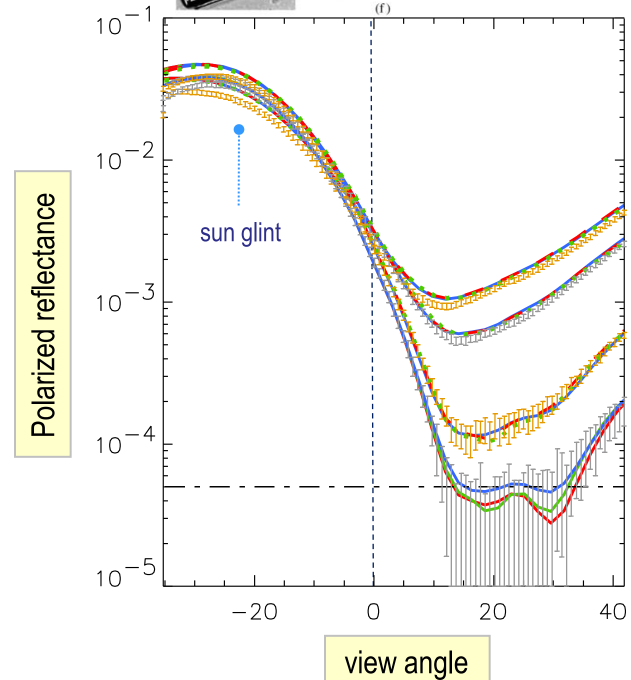
Pre-Aerosol Cloud ocean Ecology mission

Objective: Determine aerosol composition, size and shape to allow unambiguous determination of their radiative effect.

Current Status: Current primary product is aerosol optical depth, which is insufficient to effectively constrain radiative effect of aerosols and can be biased by errors in assumed aerosol composition and size.

Approach: Make multi-angle polarization measurements from near UV to SWIR.





Understanding Radiative Feedbacks

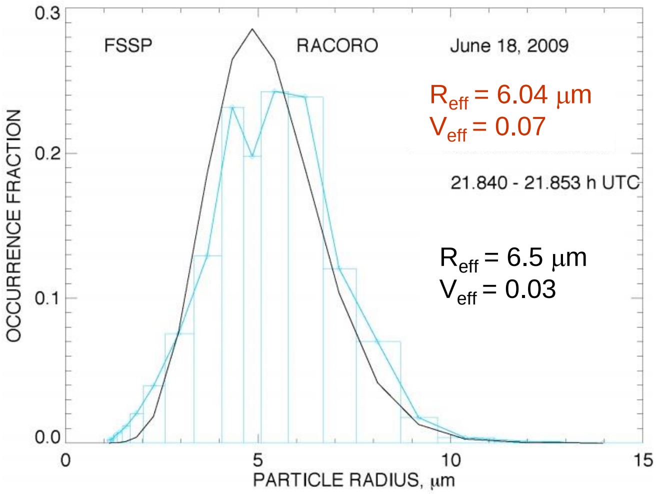
PACE

Pre-Aerosol Cloud ocean Ecology mission

Objective: Determine cloud droplet size distributions without biases caused by cloud structure and ice crystal aspect ratio and roughness that control radiative effect of ice clouds.

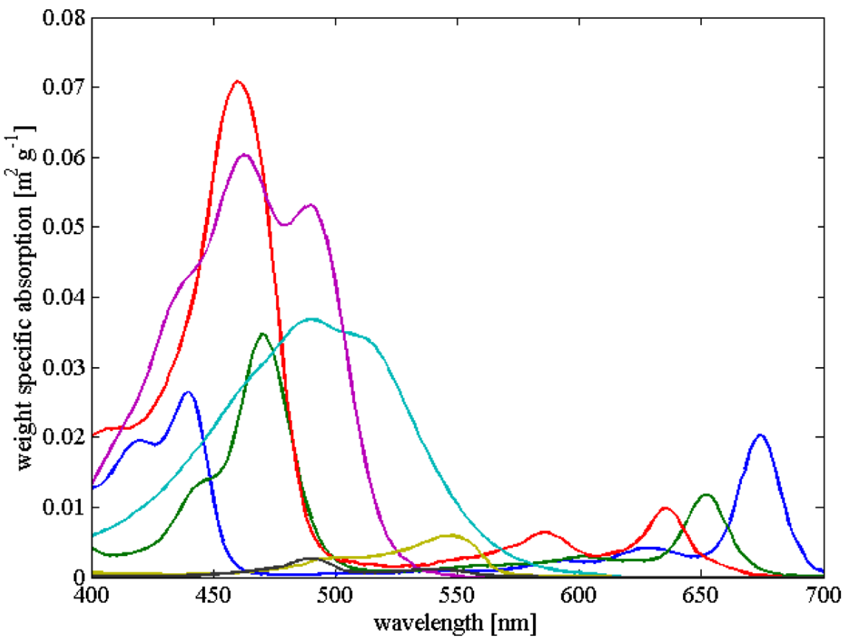
Current Status: Droplet effective radius is determined by MODIS/VIIRS, but can be affected by three-dimensional cloud structures and/or heterogeneity.

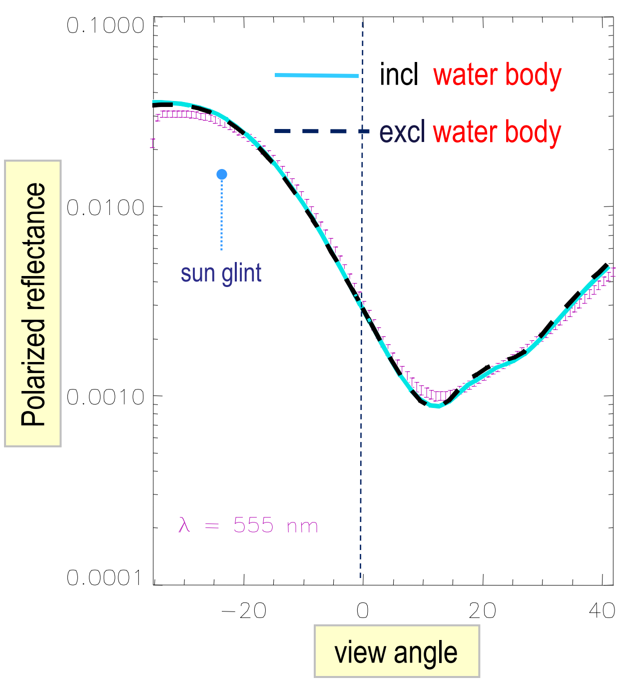
Approach: Multi-angle polarization measurements of the rainbow for water clouds and the polarized reflectance for ice clouds can be used for this purpose.



Scientific synergy

- Significant synergies exist between ocean color remote sensing and a polarimetric sensor
  - Polarimeters make measurements that are only weakly sensitive to ocean color and can therefore be used for atmospheric correction that facilitates speciation of phytoplankton.
  - Ocean color sensor allows identification of species and phytoplankton pigments improving the aerosol retrieval capability by defining the relative spectral absorption.





Science Questions to Data Products

PACE

Pre-Aerosol Cloud ocean Ecology mission

PACE Baseline

Current primary atmosphere products from ocean color sensor

- Aerosol
  - Optical depth
  - Angstrom exponent

- Cloud
  - Optical depth
  - Particle size for ice and water clouds
  - Cloud top height – uses temperature
  - Thickness/Droplet concentration – adiabatic assumption

Polarimeter atmosphere products

- Aerosol
  - Particle size distribution - accumulation and coarse modes
  - Complex spectral refractive index
  - Optical depth
  - Mixed layer/aerosol layer height

All products available over land, ocean, clouds and snow and ice

- Cloud
  - Optical depth
  - Droplet size distribution at cloud top for water clouds
  - Particle size for ice and water clouds
  - Cloud top height – uses pressure
  - Thickness/Droplet concentration – no assumption
  - Ice crystal aspect ratio/roughness

Polarimeter

Candidates:

- SPEX from Netherlands (maturity)
- 3MI from ESA (performance)
- MSPI, or variant thereof from JPL (cost)

PACE Atmospheric Science

PACE

Pre-Aerosol Cloud ocean Ecology mission

What are the benefits of flying a polarimeter with PACE?

•As identified in NASA's strategic plans a high performance polarimeter can "extend data records on aerosols and clouds"

- In particular the measurements provided by a high performance polarimeter provide their own unique contribution to advancing our understanding of climate because they are the only realistic approach to reducing uncertainties in the radiative forcing of climate by aerosols.
- There are significant synergies with an ocean color instrument in terms of improving both atmospheric correction of the ocean color observations and reducing uncertainties in aerosols retrievals caused by limitations in polarized bio-optical models of the ocean
- Improving quantification of fertilization effects by estimating the iron available from dust regionally
- Aerosol speciation to understand aerosol generations by the oceans and aerosol deposition into the oceans

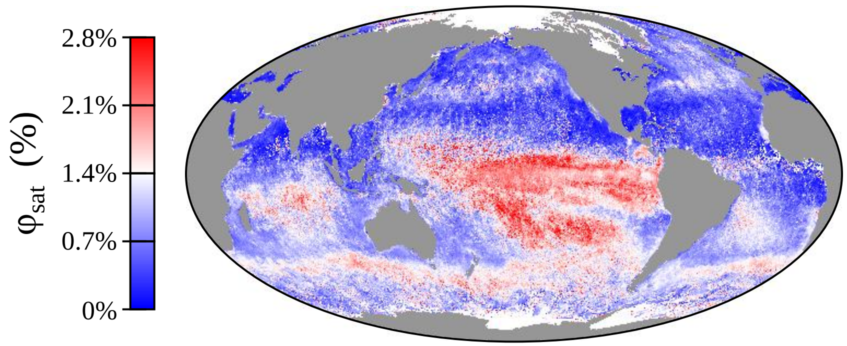
•PACE with ocean color and polarimeter greatly increases science scope & community support

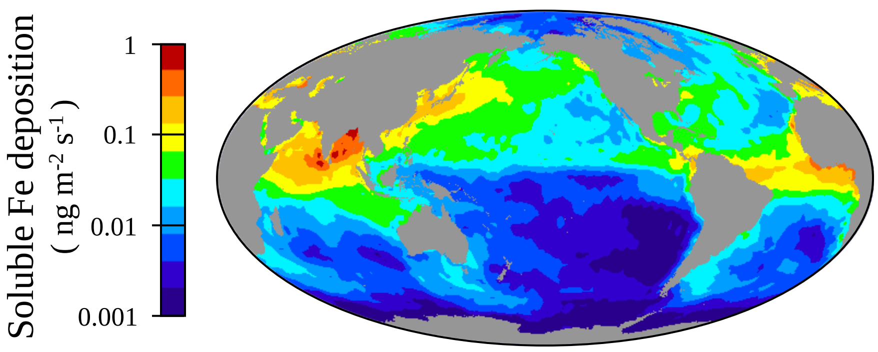
- ***Delivery of two mutually- supporting science product streams - ocean color and aerosols - at low cost and on an accelerated schedule.***

Scientific synergy

- Ocean color sensor allows identification of phytoplankton stress through measurements of fluorescence line height.

- Polarimeter quantifies absorption by dust aerosols allowing co-incident estimates of iron content.





PACE Terrestrial Science: At no cost!

PACE

Pre-Aerosol Cloud ocean Ecology mission

"PACE, by providing frequent global moderate-resolution observations with numerous spectral bands, will provide new global products of terrestrial ecosystems that will be directed at a number of science questions (see below). These capabilities meet requirements of the Decadal Survey, which identifies the following terrestrial ecosystem properties as key:

- Distribution and changes in key species and functional groups of organisms
- Disturbance patterns
- Vegetation stress
- Primary productivity
- Vegetation cover"

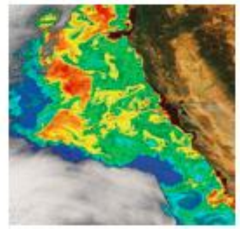
Quotation from PACE SDT report

Terrestrial science questions:

1. What are the structural and biochemical characteristics of plant canopies? How do these characteristics affect carbon, water, and energy fluxes?
2. What are the seasonal patterns and shorter-term variations in terrestrial ecosystems, functional groups, and diagnostic species? Are short-term changes in plant biochemistry the early signs of vegetation stress and do they provide an indication of an increased probability of serious perturbations?
3. What are the global spatial patterns of ecosystem and biodiversity distributions, and how do ecosystems differ in their composition? Can differences in the response of optical signals to environmental changes improve the ability to map species, characterize species diversity, and detect occurrence of invasive species?

PACE: Science Team meetings

Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) LRD 2018



The Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) mission will make essential global ocean color measurements, essential for understanding the carbon cycle and how it both affects and is affected by climate change, along with polarimetry measurements to provide extended data records on clouds and aerosols.

"*The PACE mission will extend key climate data records whose future was in jeopardy prior to the FY2011 budget request. Global ocean color measurements, essential for understanding the carbon cycle and how it affects and is affected by climate change, will be made by a radiometer instrument on this mission. A polarimeter instrument will extend data records on aerosols and clouds using this approach begun by the French PARASOL mission and expanded upon by NASA's Glory mission, as well as multi-spectral and multi-angle measurements made by NASA's MODIS and MISR instruments on NASA's EOS platforms (MODIS on terra and Aqua, MISR on Aqua)*."

- In autumn of 2011 NASA convened a science definition team (SDT) to provide the science justification and measurement, as well as mission requirements, for the PACE mission
- It was decided that the primary emphasis of the PACE mission should be on ocean sciences, and the secondary emphasis on atmospheric sciences

PACE: Science Team meetings

PACE

Ocean Science

Atmosphere Science

Option	*Science Threshold and Goal Questions*	*Brief Instrument Description*
OCI †	➢ **Threshold** Ocean Questions SQ 1-7 ➢ Goal Terrestrial Questions TSQ 1-3 *Note*: **Threshold** Questions define required research, i.e. they <u>must</u> be addressed	○ Hyperspectral imager with 5 nm resolution between $\boxed{350}$-800 nm ○ 2 NIR bands (incl. 865 nm) ○ 3 SWIR bands (1240, 1640, 2130 nm) ○ spatial resolution = 1 km^2
OCI/OG	➢ OCI Questions (SQ 1-7, TSQ 1-3) ➢ Goal Coastal Questions CSQ 1-4	○ OCI instrument capabilities ○ hyperspectral between 800-900 nm, 1-2 nm subsamples (O_2 A) ○ improved global coverage (1 day) ○ spatial resolution better than 500m × 500m
OCI+	➢ OCI Questions (SQ 1-7, TSQ 1-3) ➢ "**Threshold**" Atmosphere Question ASQ 1	○ OCI instrument capabilities ○ 3 additional NIR and SWIR bands (940, 1378, 2250 nm)
OCI-3M ¶	➢ OCI Questions (SQ 1-7, TSQ 1-3) ➢ Goal Atmosphere Questions ASQ 4,5	○ OCI instrument capabilities ○ a 3M imager ‡ §
OCI/A	➢ OCI+ Questions (SQ 1-7, TSQ 1-3, ASQ 1) ➢ Goal Atmosphere Question ASQ 2	○ OCI+ instrument capabilities ○ selected atmospheric bands at spatial resolution 250m × 250m
OCI/A-3M	➢ OCI-3M & OCI/A Questions (SQ 1-7, TSQ 1-3, ASQ 2,4,5) ➢ Goal Atmosphere Question ASQ 3	○ OCI/A instrument capabilities ○ a 3M imager ‡ §

SQ 1-7: ocean ecosystems
- biochemical cycles
- biological processes
- anthropogenic effects

TSQ 1-3 : terrestrial ecology
- plant biochemistry
- biodiversity

CSQ 1-4: coastal ocean
- biochemical cycles
- biodiversity
- terrestrial effects

ASQ 1: heritage data records for aerosols and clouds (MODIS, MISR, VIIRS)

ASQ 4: aerosol direct forcing

ASQ 5: aerosol → ocean

ASQ 2: aerosol → cloud

ASQ 3: cloud → aerosol

† *OCI = Ocean Color Imager*

¶ *3M = Multi-directional, Multi-polarization, Multi-spectral*

‡ *improved atmospheric correction, data continuity for POLDER products*

§ *data continuity for MISR products, albeit with coarser spatial resolution*

PACE: Science Team meetings

PACE

Ocean Science

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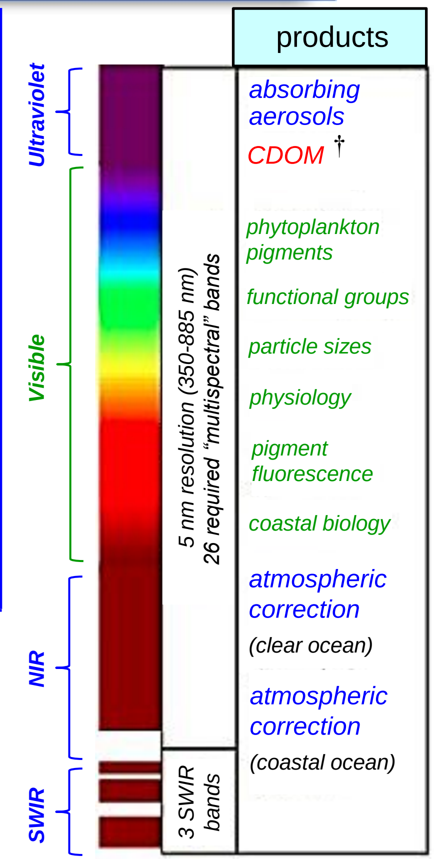


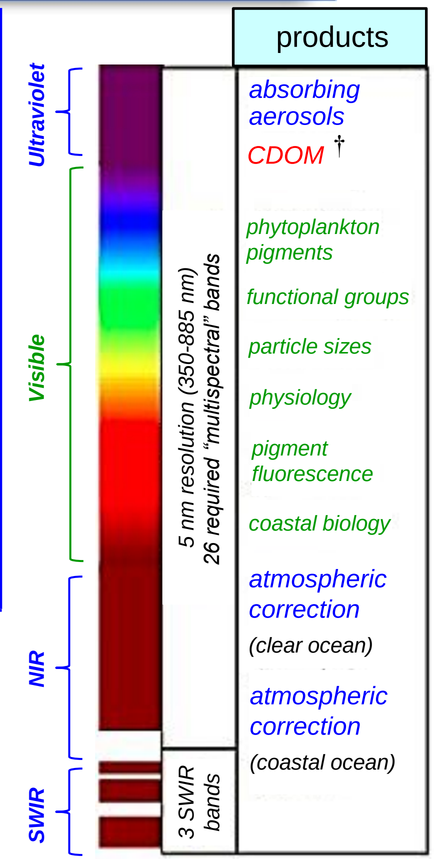
† CDOM = Colored Dissolved Organic Matter

PACE: Science Team meetings

PACE

Ocean Science

Option	Science Threshold and Goal Questions	Brief Instrument Description
OCI †	➢ **Threshold** Ocean Questions SQ 1-7 ➢ Goal Terrestrial Questions TSQ 1-3 *Note*: **Threshold** Questions define required research, i.e. they must be addressed	○ Hyperspectral imager with 5 nm resolution between 350-800 nm ○ 2 NIR bands (incl. 865 nm) ○ 3 SWIR bands (1240, 1640, 2130 nm) ○ spatial resolution = 1 km^2
OCI/OG	➢ OCI Questions (SQ 1-7, TSQ 1-3) ➢ Goal Coastal Questions CSQ 1-4	○ OCI instrument capabilities ○ hyperspectral between 800-900 nm, 1-2 nm subsamples (O_2 A) ○ improved global coverage (1 day) ○ spatial resolution better than 500m × 500m



† CDOM = Colored Dissolved Organic Matter

ocean science products → Ocean science threshold and goal questions (SQ 1-7 and CSQ 1-4)

- retrieve reflectance ρ_w (λ) of water-leaving radiance within an accuracy of 5% (or 0.001) from space in the VIS
- retrieve reflectance ρ_w (λ) of water-leaving radiance within an accuracy of 10% (or 0.002) from space in the UV

Note: contribution of ρ_w (λ) to top-of-atmosphere reflectance ρ_{tot} (λ) is typically less than 15% in VIS…

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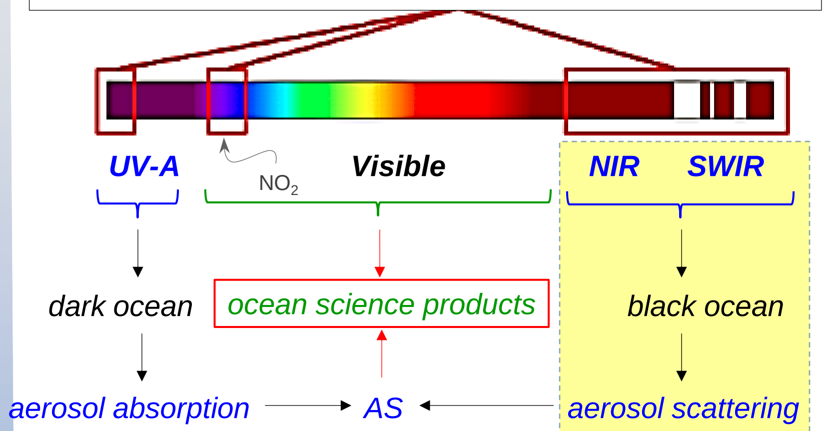
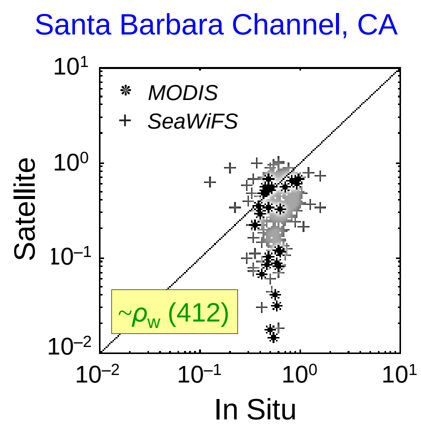
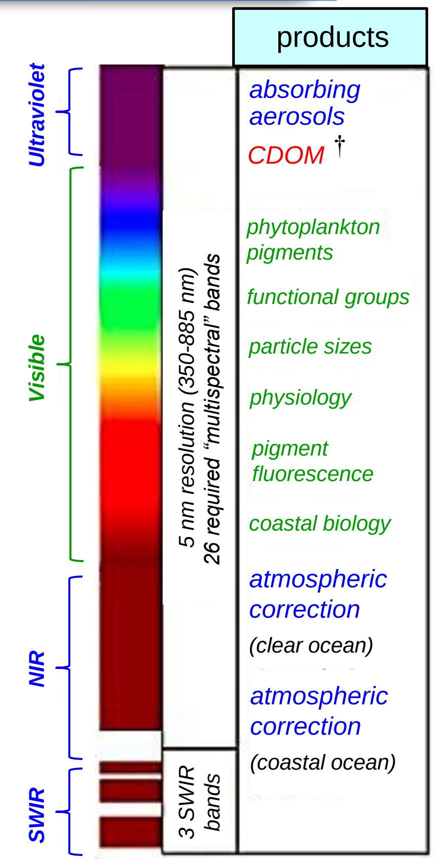
Atmospheric Scattering (AS) estimate

NIR & SWIR band ratios: select aerosol scattering model
UV-A radiance: detect (& constrain?) aerosol absorption







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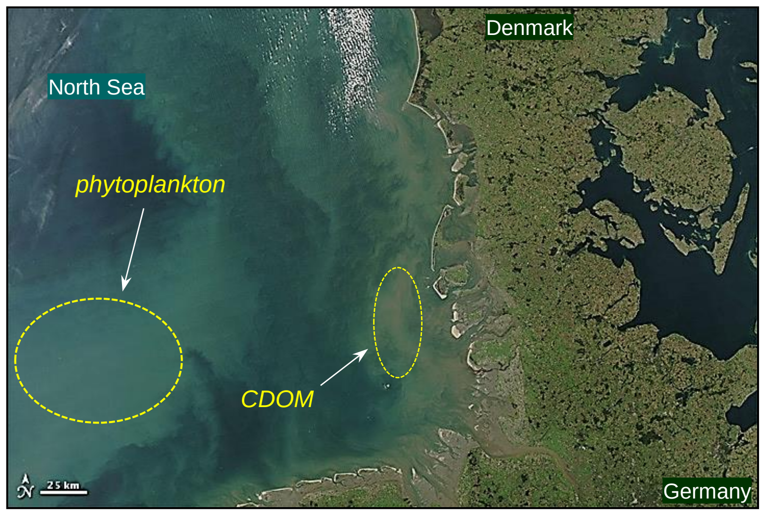
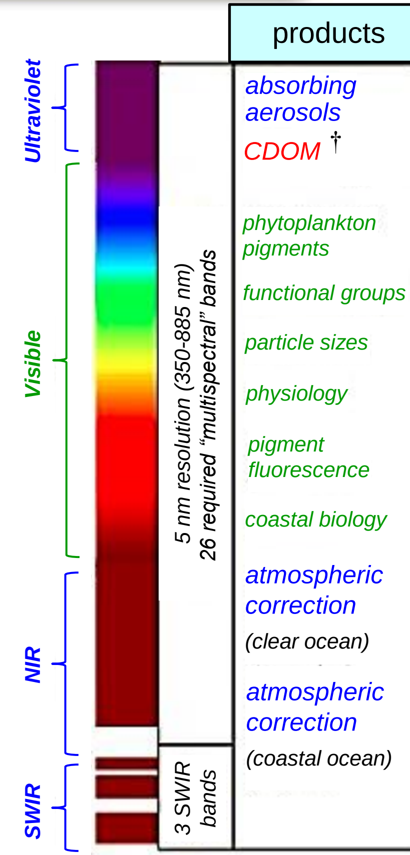
CDOM ("gelbstoff"):

- complex organic chemical compounds
- coastal/inland: breakdown of natural materials
- open ocean: produced by heterotrophic activity
- affects the color of the ocean →
  influences the retrieval of phytoplankton pigments

MODIS, Oct 2011





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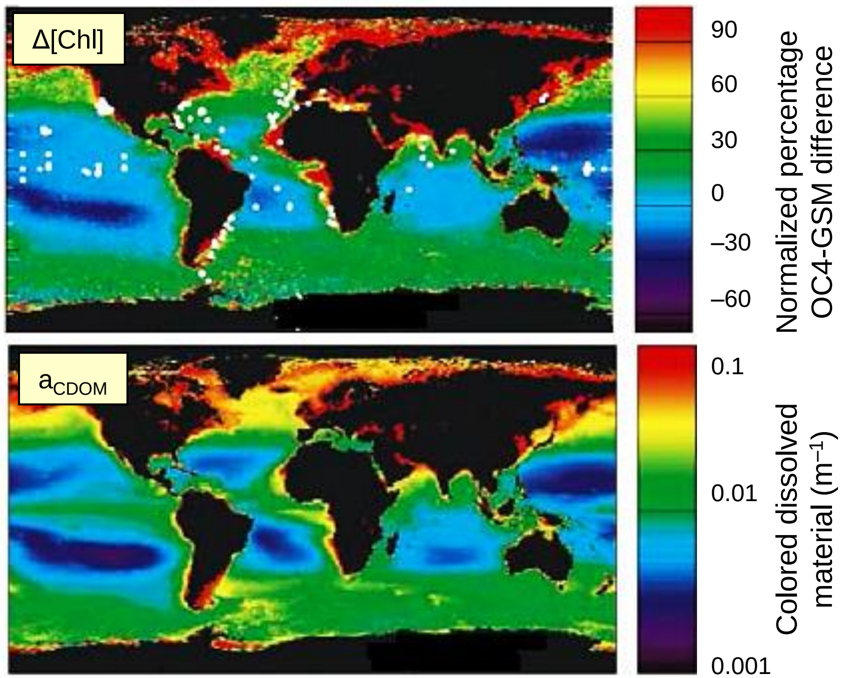

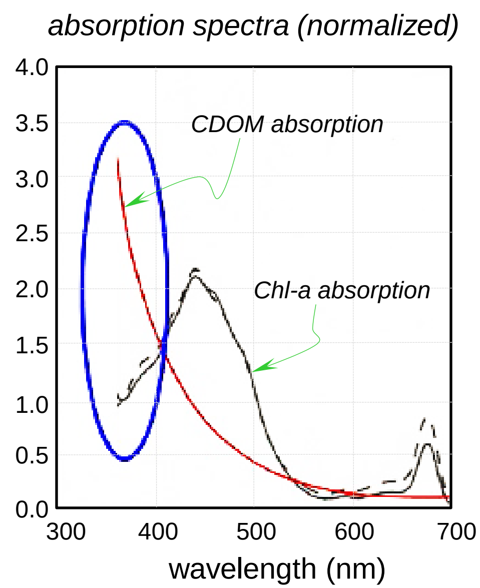

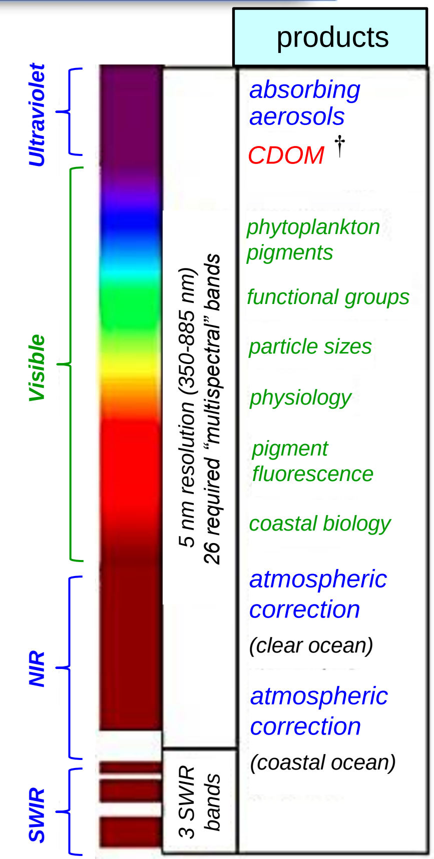

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Atmospheric Scattering (AS)

NIR & SWIR band ratios: select aerosol scattering model
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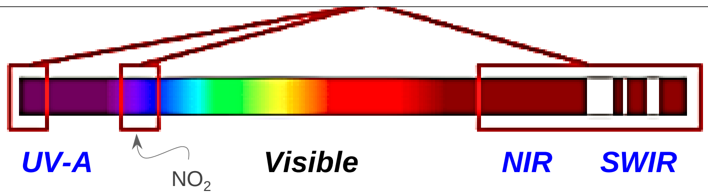
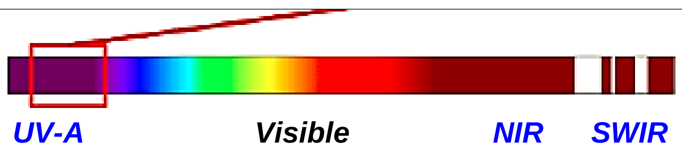


CDOM

UV-A radiance: retrieve CDOM absorption (and spectrum)



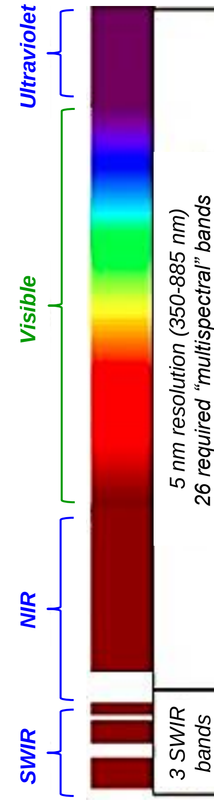
- When is the ocean dark enough to retrieve variations in aerosol absorption?

  λ = 350 nm † (?)

- When is the ocean bright enough to retrieve variations in CDOM?

  λ = 385 nm † (?)

† 3MI *originally included 354 and 388 nm*



products
absorbing aerosols
CDOM †
phytoplankton pigments
functional groups
particle sizes
physiology
pigment fluorescence
coastal biology
atmospheric correction (clear ocean)
atmospheric correction (coastal ocean)

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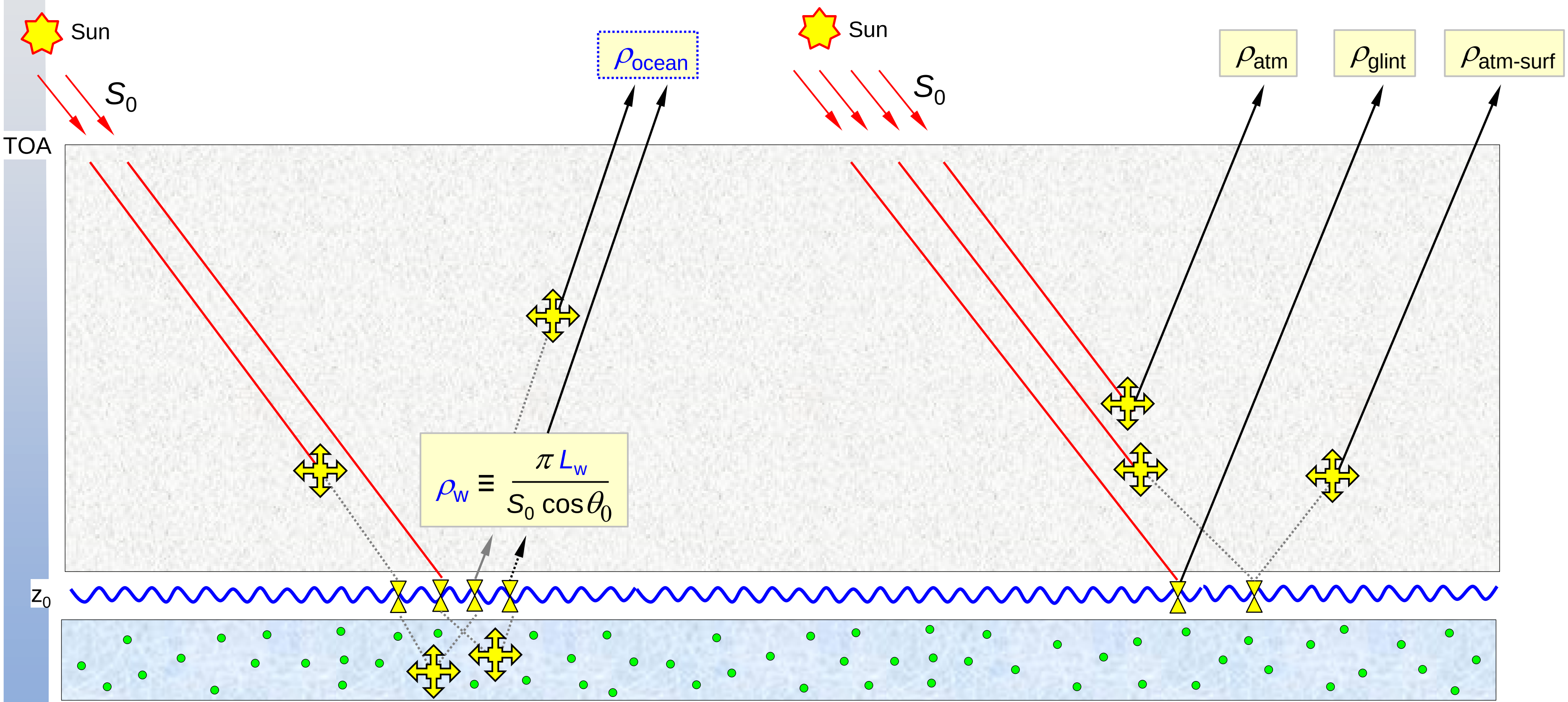
Radiative Transfer (RT) computations Doubling-Adding method for multiple scattering of polarized light

$$\rho\,(\mathrm{TOA}) \equiv \boxed{\rho_{\mathrm{TOA}} = \rho_{\mathrm{atm}} + \rho_{\mathrm{atm\text{-}surf}} + \rho_{\mathrm{glint}} + \rho_{\mathrm{ocean}}} \Rightarrow \boxed{\rho_{\mathrm{ocean}}\,(\%) \equiv \rho_{\mathrm{ocean}} \,/\, \rho_{\mathrm{TOA}}}$$



multiple scattering
(incl. 1st order scatter)

surface interaction
(incl. wave shadowing)

repeated interactions

direct transmission

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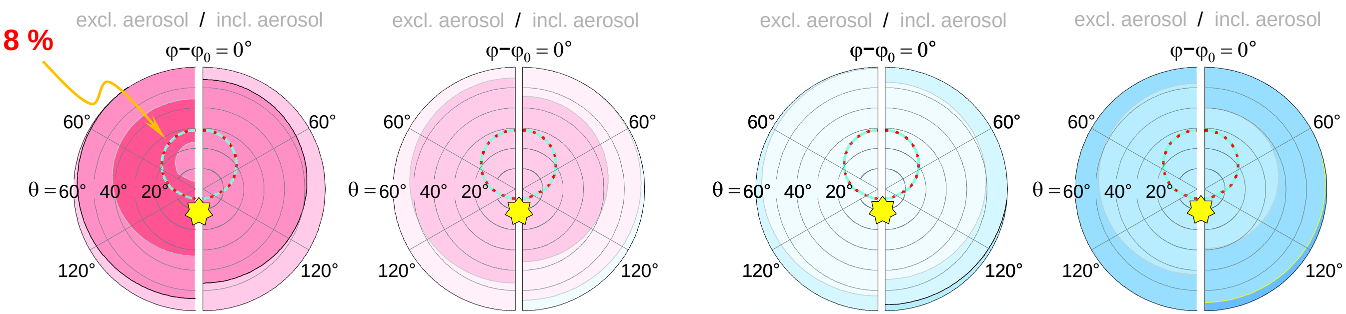
Sensitivity Study Results

At 350 nm, the ocean can be too bright for some cases

[Chl] = 0.03 *(Global ocean)*

[Chl] = 1.00 *(Global ocean)*

~ 8 %



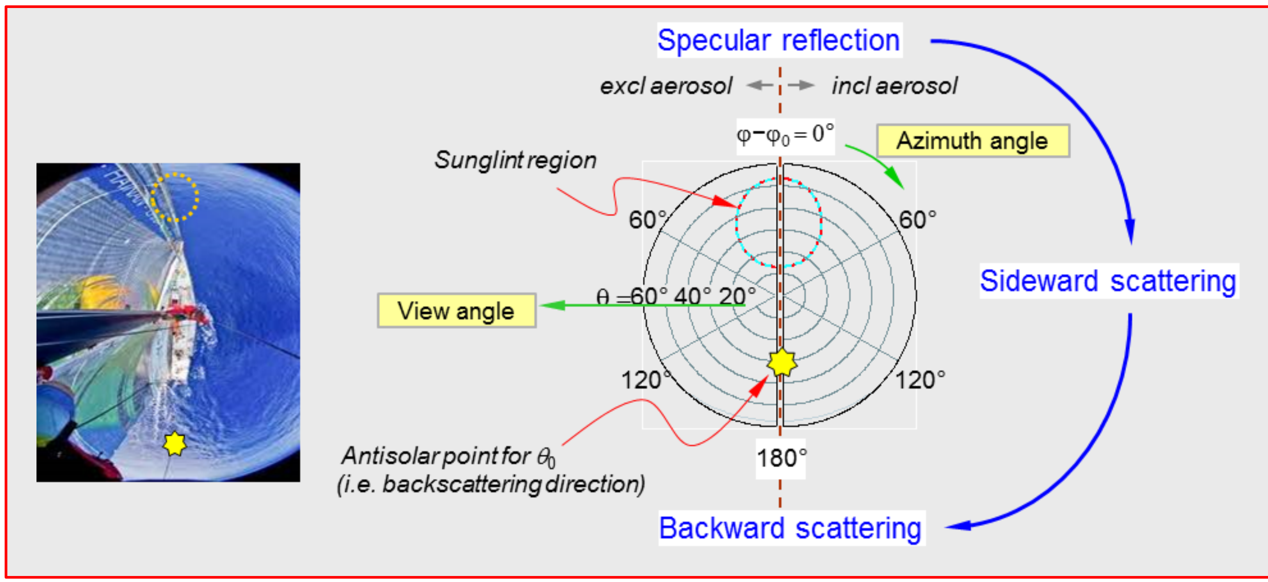
ρ_{ocean} (%) ≡ ρ_{ocean} / ρ_{TOA}

$$\rho = \{\sqrt{Q^2+U^2} + (I - \sqrt{Q^2+U^2})\} / F$$

$$\equiv \rho_P + \rho_{XP}$$

Stokes parameters = I, Q, U

Normalized flux $F = (S_0 \cos\theta_0) / \pi$



[Chl] = 0.03 mg/m3 [Chl] = 0.10 mg/m3 [Chl] = 0.30 mg/m3 [Chl] = 1.00 mg/m3

ρ_{ocean} (%) (350 nm) ρ_{ocean} (%) (350 nm)

$$\frac{\rho_{ocean}}{\rho_{TOA}} = \frac{\rho_{ocean,P}}{\rho_{TOA,P}} + \frac{\rho_{ocean,XP}}{\rho_{TOA,XP}}$$

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Sensitivity Study Results

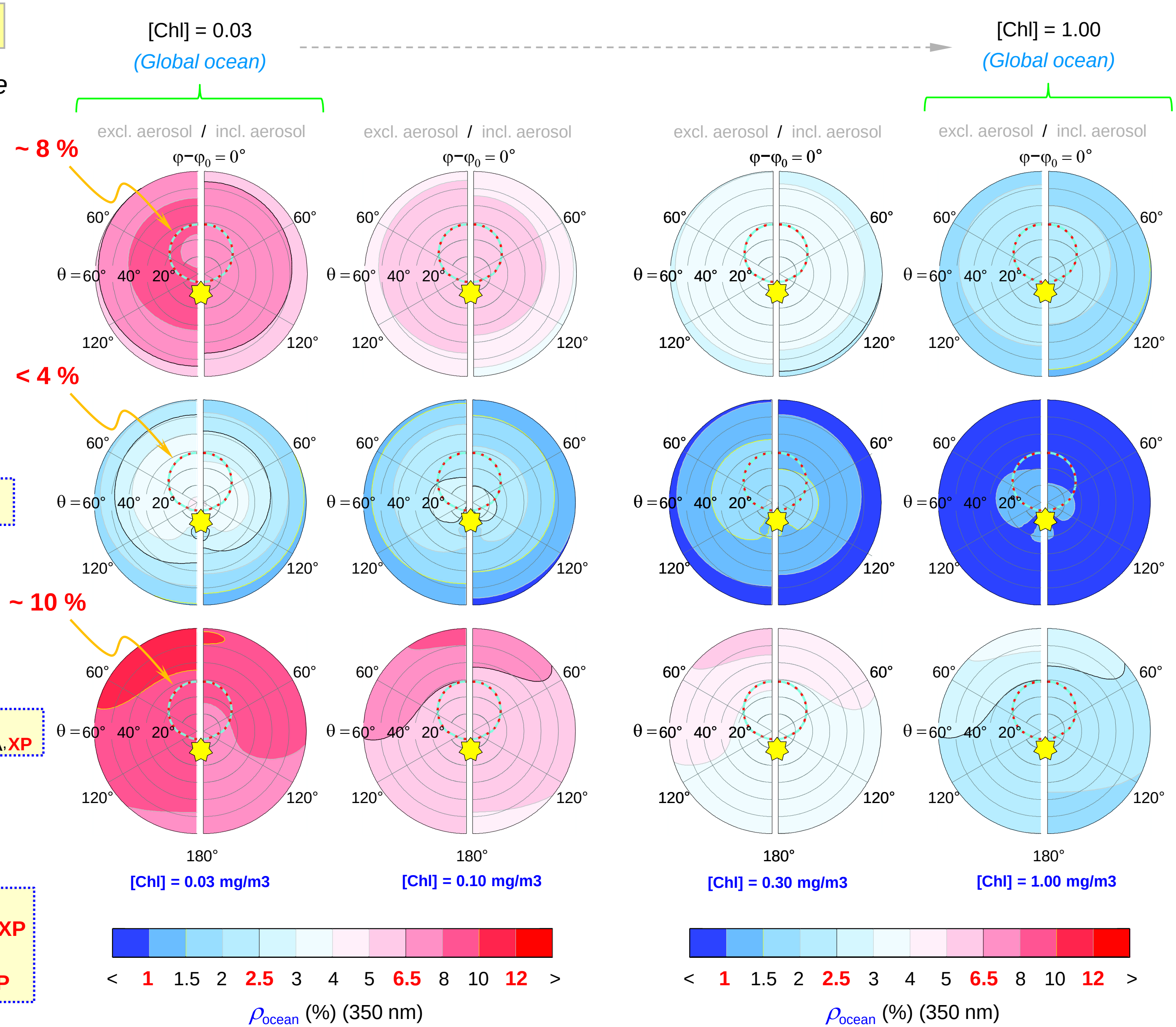
At 350 nm, the ocean can be too bright for some cases

$\rho_{ocean}\,(\%) \equiv \rho_{ocean} / \rho_{TOA}$

$\rho_{ocean,P}\,(\%) \equiv \rho_{ocean,P} / \rho_{TOA,P}$

$\rho_{ocean,XP}\,(\%) \equiv \rho_{ocean,XP} / \rho_{TOA,XP}$

$$\frac{\rho_{ocean}}{\rho_{TOA}} = \frac{\rho_{ocean,P}}{\rho_{TOA,P}} + \frac{\rho_{ocean,XP}}{\rho_{TOA,XP}}$$



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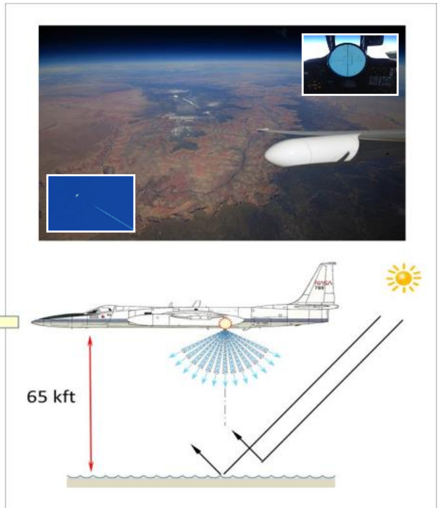
Field experiments



AVIRIS data collected over Monterey Bay (CA)

AVIRIS data:

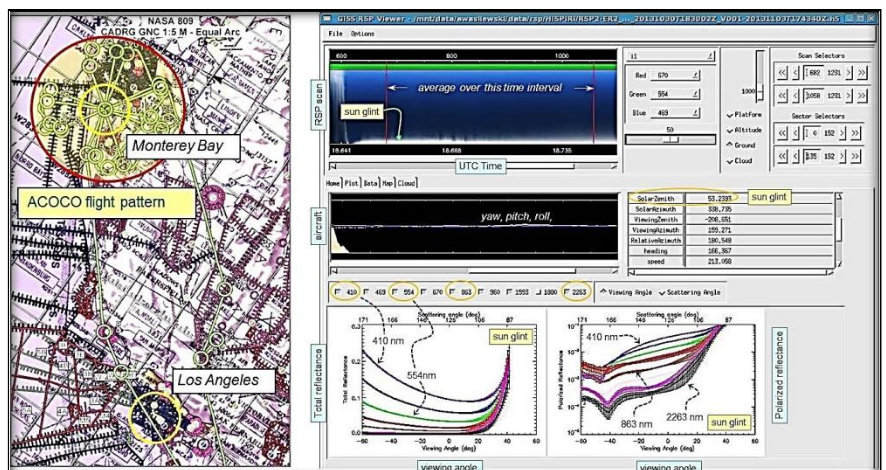
- Stokes parameter *I* (intensity)
- Scans 677 pixels across track (1 angle)
- 224 hyperspectral channels (0.38-2.5 μm)
- 1 mrad IFOV (≈20 m spatial resolution)

RSP data:

- Stokes parameters *I*, *Q* & *U*
- Scans along ground track 152 angles (±60 deg)
- 9 narrow-wavelength bands (410-2250 nm)
- 14 mrad IFOV (≈ 280 m spatial resolution)

ER-2 aircraft

- 65,000 ft flight altitude



How can multiangle polarimetry help ocean retrievals?

1. Case I (open) waters: Atmospheric correction in VIS & UV

Table 6

Simulated change with [Chl] in reflectance, evaluated at top of the atmosphere and averaged over a scan of $-60° \leq \theta \leq 60°$, for ground track and solar angle of RSP file 55. The atmosphere contains either the aerosol modes for RSP file 55 (reflectance change shown in normal font) or no aerosol at all (reflectance change shown in italic font). The change, given both in absolute units and in percent, is relative to the case with smallest [Chl].

ρ	Δ[Chl][a]	$\lambda = 410$ nm	$\lambda = 443$ nm	$\lambda = 470$ nm	$\lambda = 490$ nm	$\lambda = 550$ nm
ρ_{pol}	$0.03 \rightarrow 1.0$	-2.6×10^{-3} (4.6%)	-2.0×10^{-3} (4.0%)	-1.5×10^{-3} (3.9%)	-8.3×10^{-4} (2.5%)	5.7×10^{-4} (2.3%)

the ocean changes from blue to green → *corresponding change in TOA VIS & UV polarized reflectance is (much) less than 4.5%*

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the ocean changes from blue to green → *corresponding change in TOA VIS & UV polarized reflectance is (much) less than 4.5%*

2. Case II (coastal) waters: oceans become bright in VIS & SWIR

→ *corresponding change in TOA polarized reflectance can be detected and inverted*

POLARIMETRIC LIGHT FIELDS IN THE OPEN OCEAN AND COASTAL WATERS AND RETRIEVAL OF WATER PARAMETERS FROM POLARIMETRIC OBSERVATIONS

Amir Ibrahim

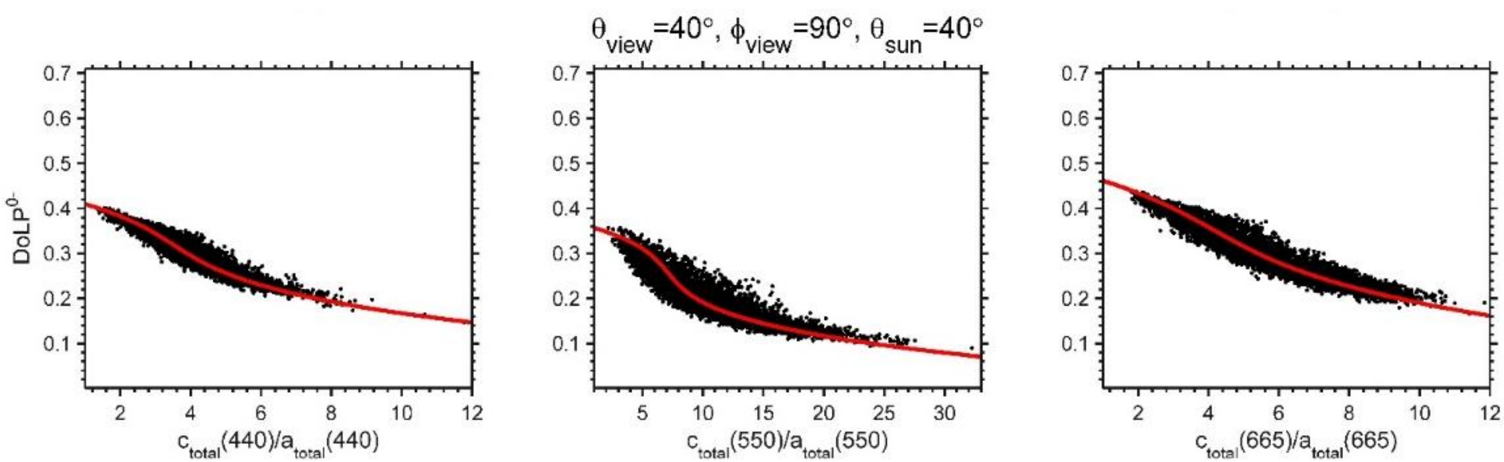
January 12th, 2015

Mentors: Professor Samir Ahmed and Professor Alexander Gilerson
Electrical Engineering Department

Results of the VRT
Case II waters
Section (IV)

Parameterization of the DoLP & *c/a* relationship

DoLP versus (c/a) ratio below water



Input

$DoLP((\boldsymbol{\theta_{sun}}, \boldsymbol{\theta_{view}}, \boldsymbol{\phi_{view}}, \boldsymbol{\lambda}))$ + Absorption coefficient $a(\lambda)$

→

Inverse algorithm

Tabulated Coefficients $p_{0\sim3}(\theta_{sun}, \theta_{view}, \phi_{view}, \lambda)$

→

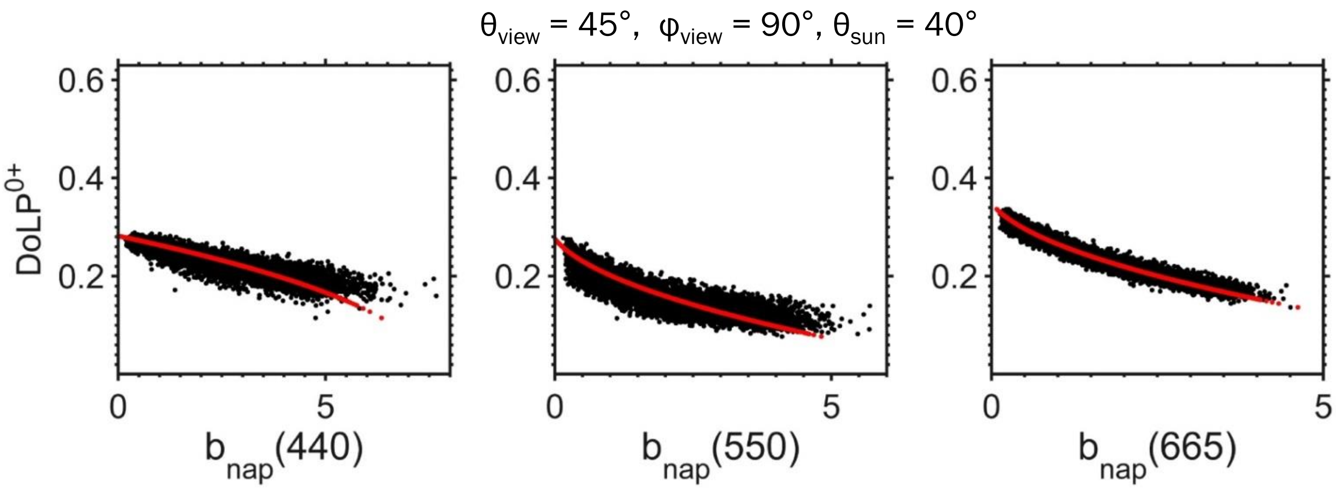
Output

Attenuation $c(\lambda)$

$b(\lambda) = c(\lambda) - a(\lambda)$

Retrieval of mineral scattering coefficient b_{nap}

DoLP versus (b_{nap}) ratio above water



Input

$DoLP((\boldsymbol{\theta}_{sun}, \boldsymbol{\theta}_{view}, \boldsymbol{\phi}_{view}, \boldsymbol{\lambda}))$ + Absorption coefficient $a(\lambda)$ →

Inverse algorithm

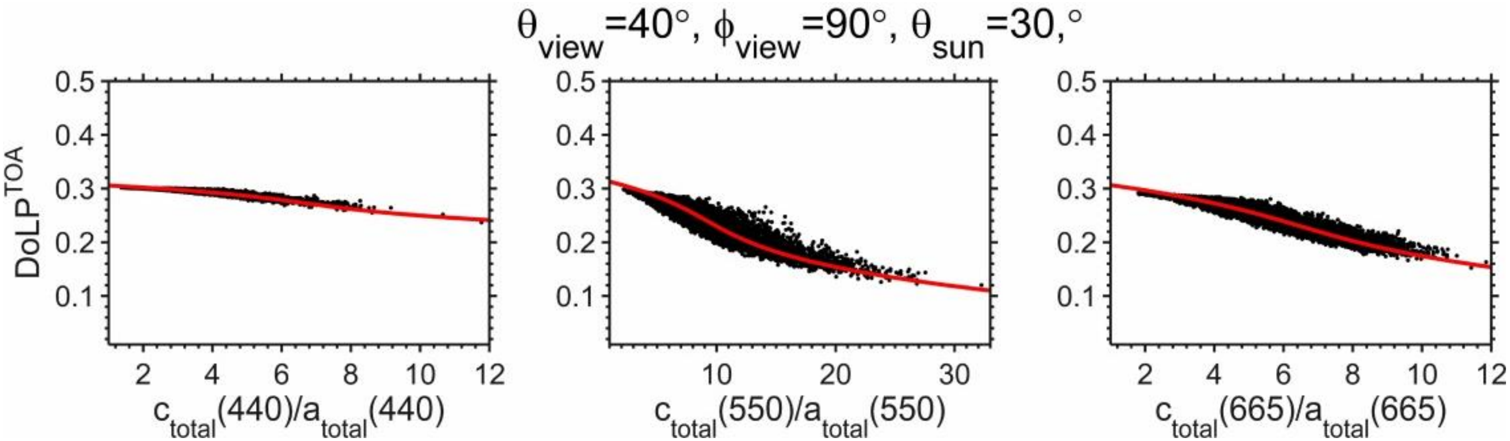
Tabulated Coefficients $p_{0\sim2}(\theta_{sun}, \theta_{view}, \phi_{view}, \lambda)$ →

Output

$b_{nap}(\lambda)$

Parameterization of the DoLP & c/a relationship

DoLP versus (c/a) ratio at TOA



The polarized TOA signal is highly affected by the single scattering by aerosols mixed with atmospheric molecules. (Moderately turbid aerosol τ=0.1)

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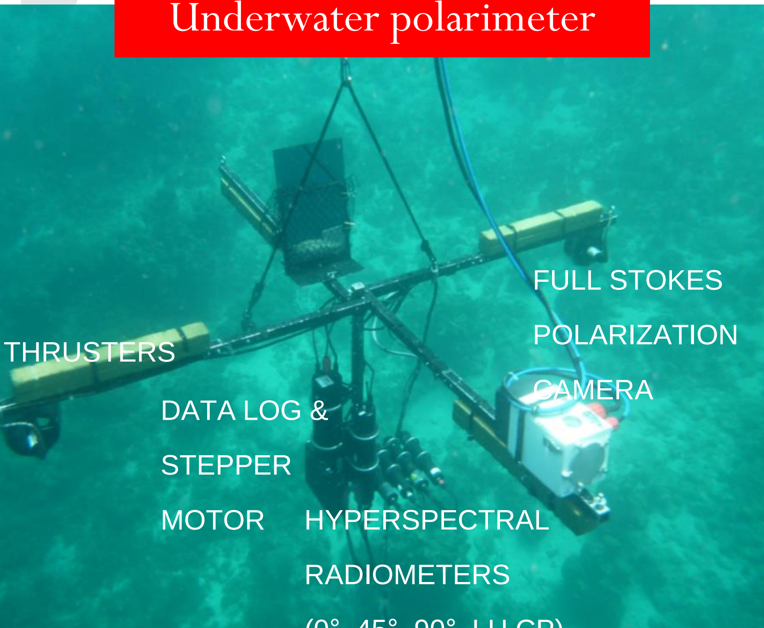
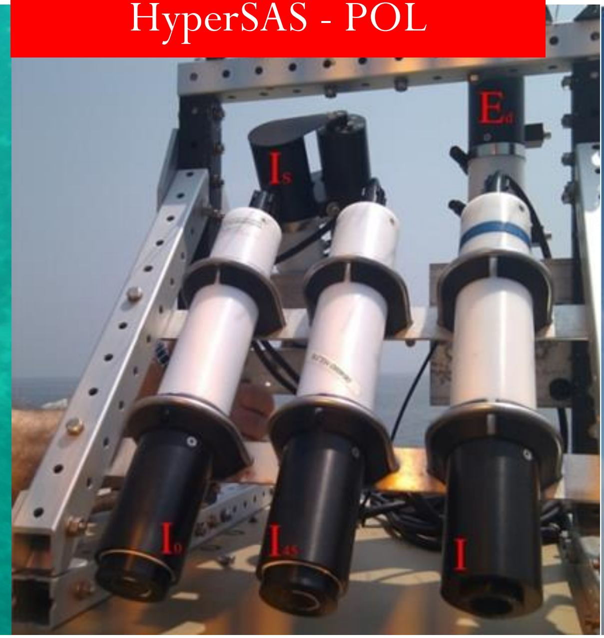
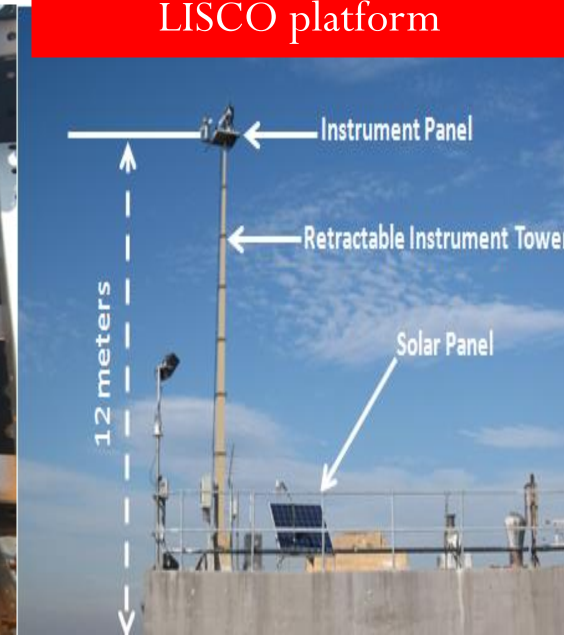
Underwater polarimeter



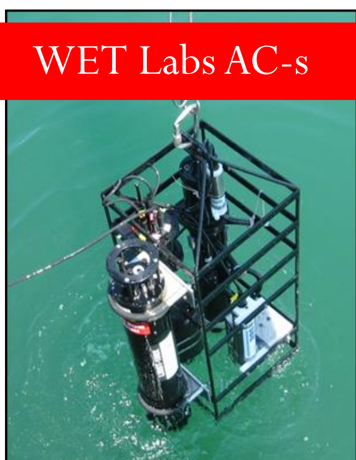
HyperSAS - POL



LISCO platform



WET Labs AC-s

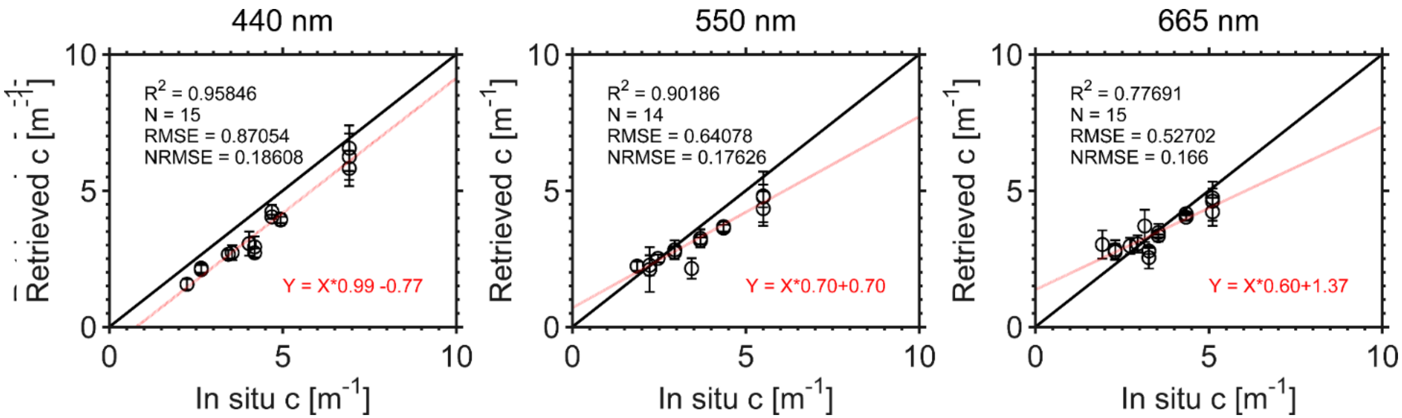


Water Quality Monitor (WQM)

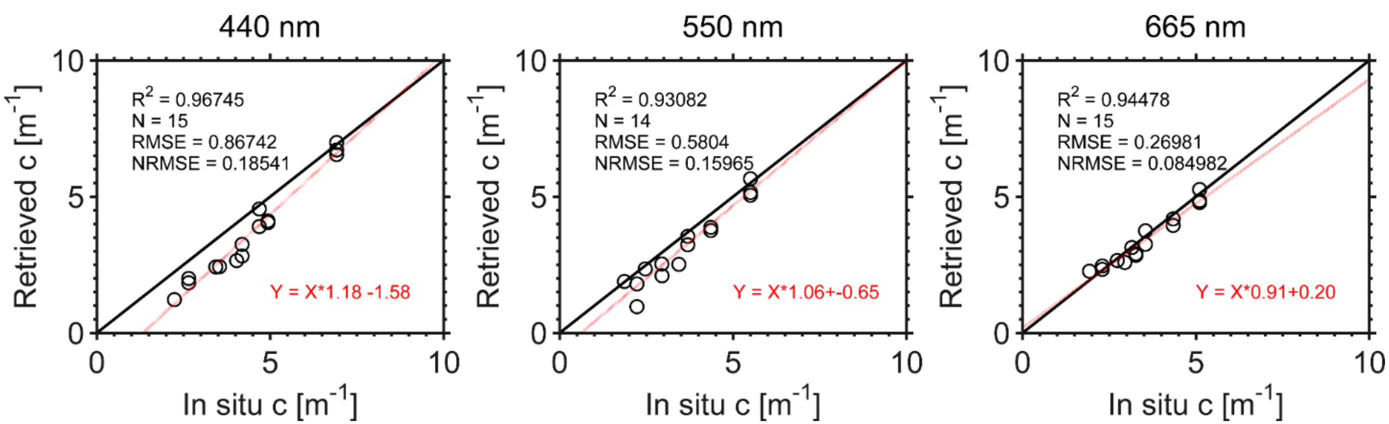
Validation

In-situ (Polarimeter vs Wetlabs) under water 1 m below *at 1 m below surface*

Average DoLP for $\theta_{view} = 40° \text{ to } 80°$



DoLP for $\theta_{view} = 75°$



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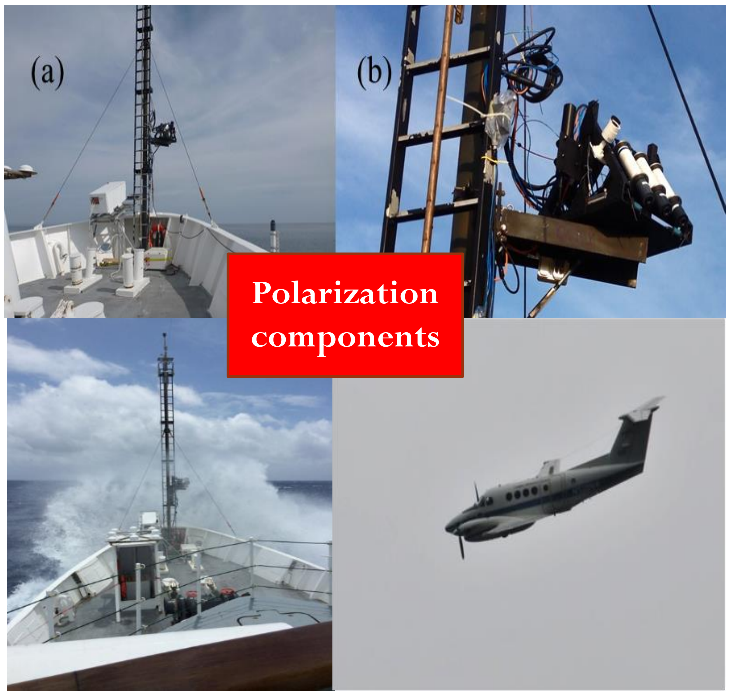
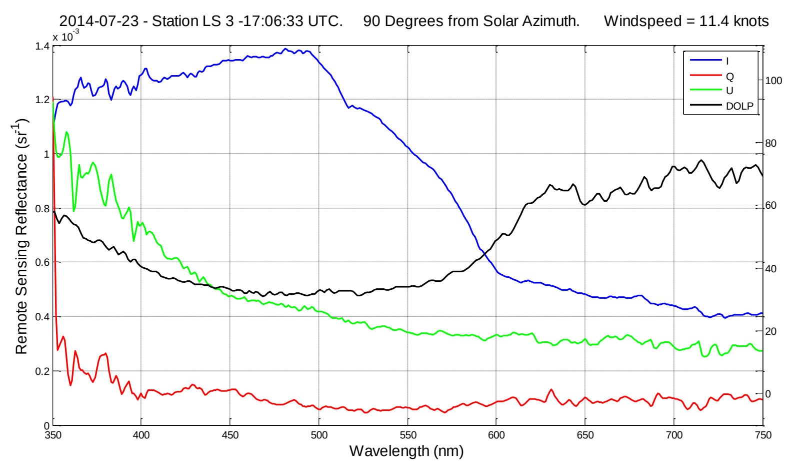
Validation: SABOR cruise in Summer 2014





Example of the HyperSAS-POL measurements of the Stokes components of the water after applying sky glint correction from the SABOR experiment.

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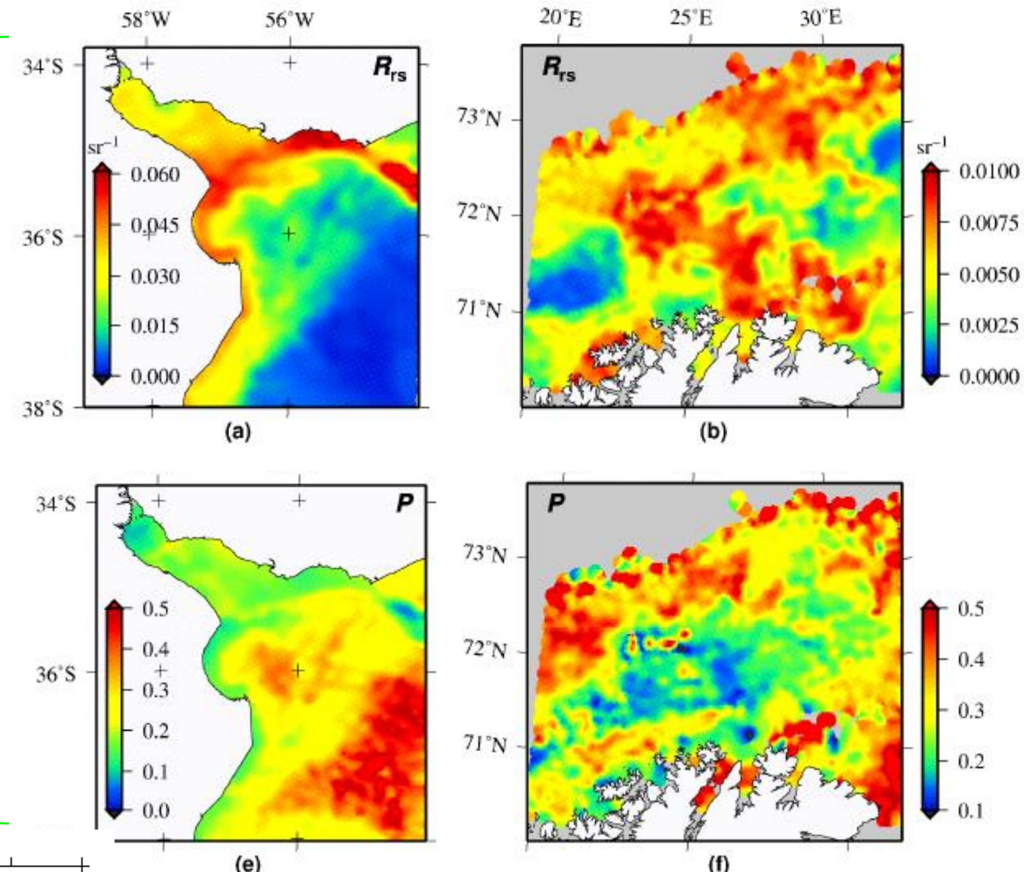
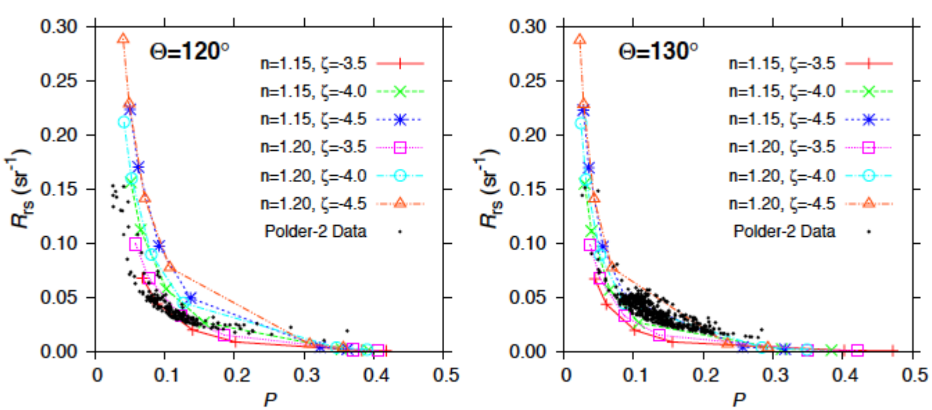
Loisel et al. (2008)

- 2 POLDER scenes
- Fits R_{rs} to P (=DoLP)

(Mediterranean Scenes chosen for no aerosol. No correction applied.)





- Then used that relationship as index in LUT to explore the retrieval of mineral properties.

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2. Case II (coastal) waters: oceans become bright in VIS & SWIR

→ retrieve *c*, *b*, NAP, n_{bulk}